



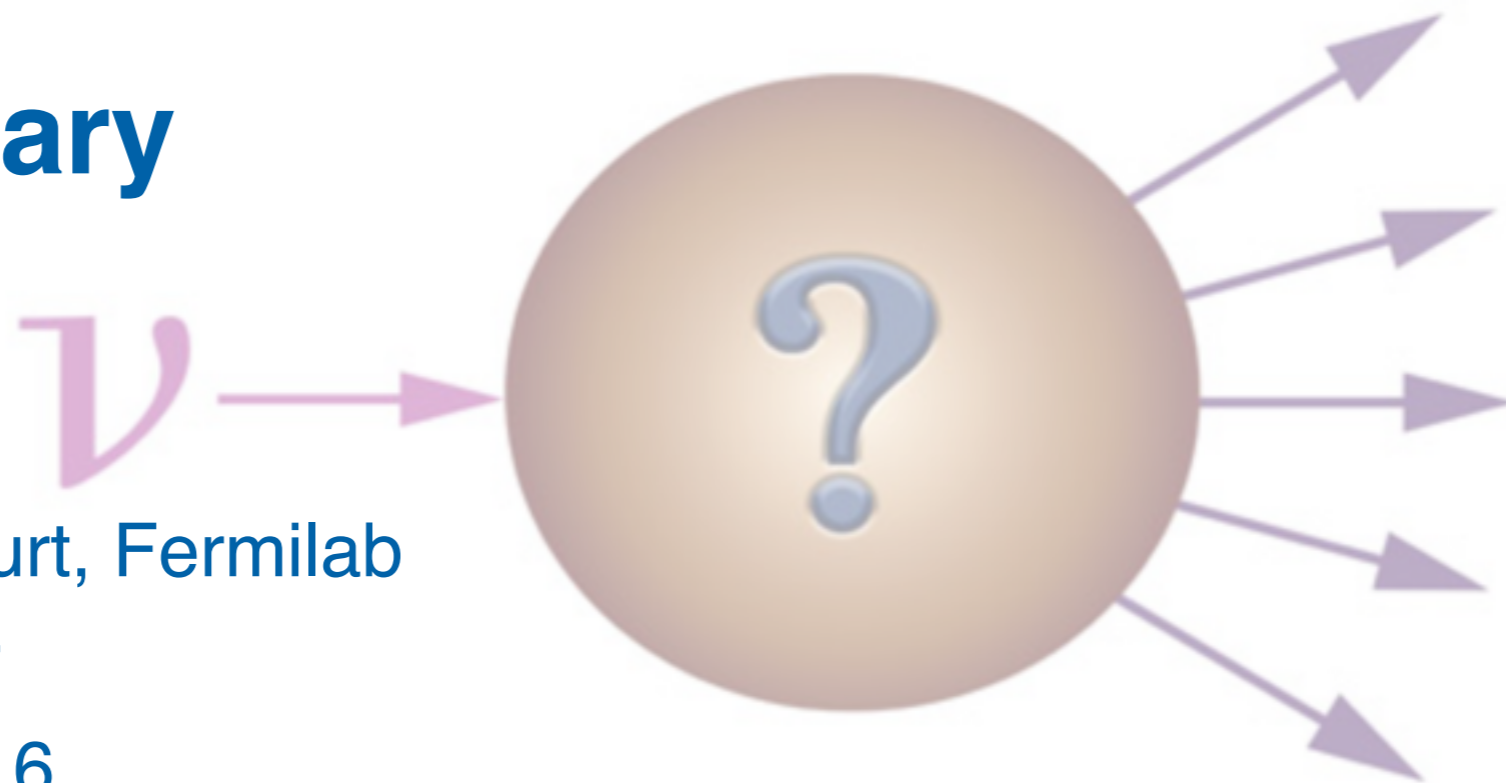
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Theoretical Developments in Neutrino-Nucleus Scattering

December 5 - 9, 2016

INT Summary

Minerba Betancourt, Fermilab
Neutrino Seminar
15 December 2016





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Programs & Workshops

► **2016 Workshops**

Theoretical Developments in Neutrino-Nucleus Scattering (INT-16-63W)
December 5 - 9, 2016
T.W. Donnelly, G.T. Garvey, H.A. Tanaka, G.P. Zeller

► **2017 Programs**

Toward Predictive Theories of Nuclear Reactions Across the Isotopic Chart (INT-17-1a)
February 27 - March 31, 2017
J.E. Escher, Ch. Elster, K.D. Launey, D. Lee

Precision Spectroscopy of QGP Properties with Jets and Heavy Quarks (INT-17-1b)
May 1 - June 8, 2017
S.A. Bass, A. Majumder, J. Putschke, L. Ruan

Neutrinoless Double-beta Decay (INT-17-2a)
June 13 - July 14, 2017
J. Engel, J. Carlson, V. Cirigliano

Electromagnetic Signatures of R-process Nucleosynthesis in Neutron Star Binary Mergers (INT-17-2b)
July 24 - August 18, 2017
R. Fernández, D. Kasen, G. Martínez-Pinedo, B.D. Metzger

Spatial and Momentum Tomography of Hadrons and Nuclei (INT-17-3)
August 28 - September 29, 2017
I. Cloët, K. Hafidi, Z.-E. Meziani, B. Pasquini

Overview

- INT workshop this year: theoretical developments in Neutrino-Nucleus Scattering
- Topics:
 - Status of neutrino experimental measurements
 - Overview of where consensus exists among the various experimental results and where discrepancies prevent a consistent explanation of the data
 - Overview of the theoretical approaches and comparisons with experimental results
- Nuclear theory, generators, electron scattering data and neutrino scattering data!

<http://www.int.washington.edu/PROGRAMS/16-63w/>

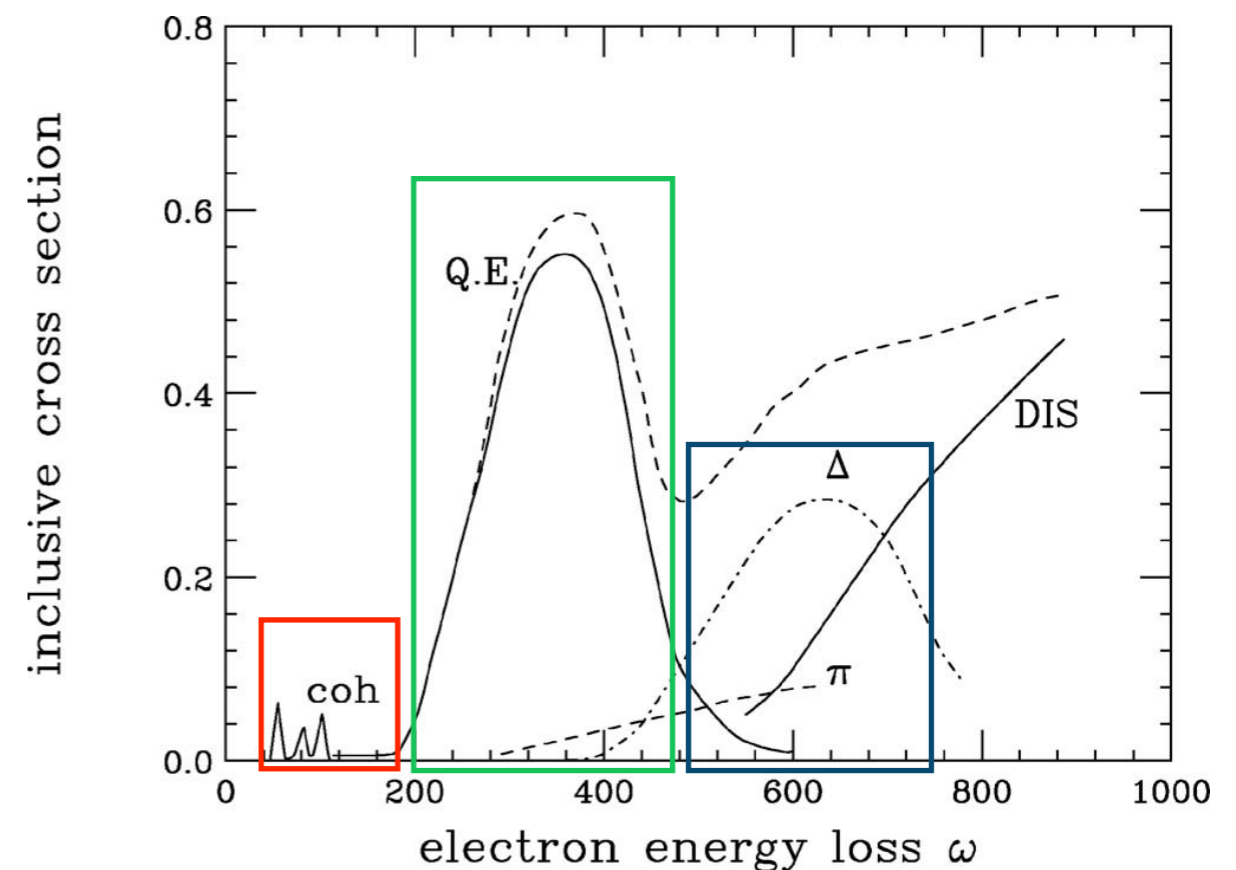
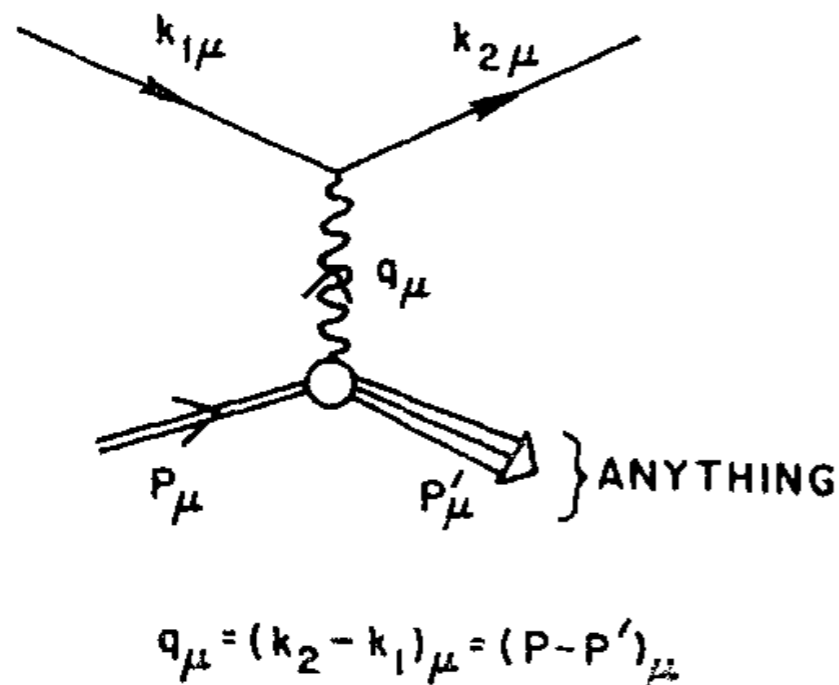


- Thanks to the speakers for the material

Pictures courtesy of Teppei

Electron Scattering

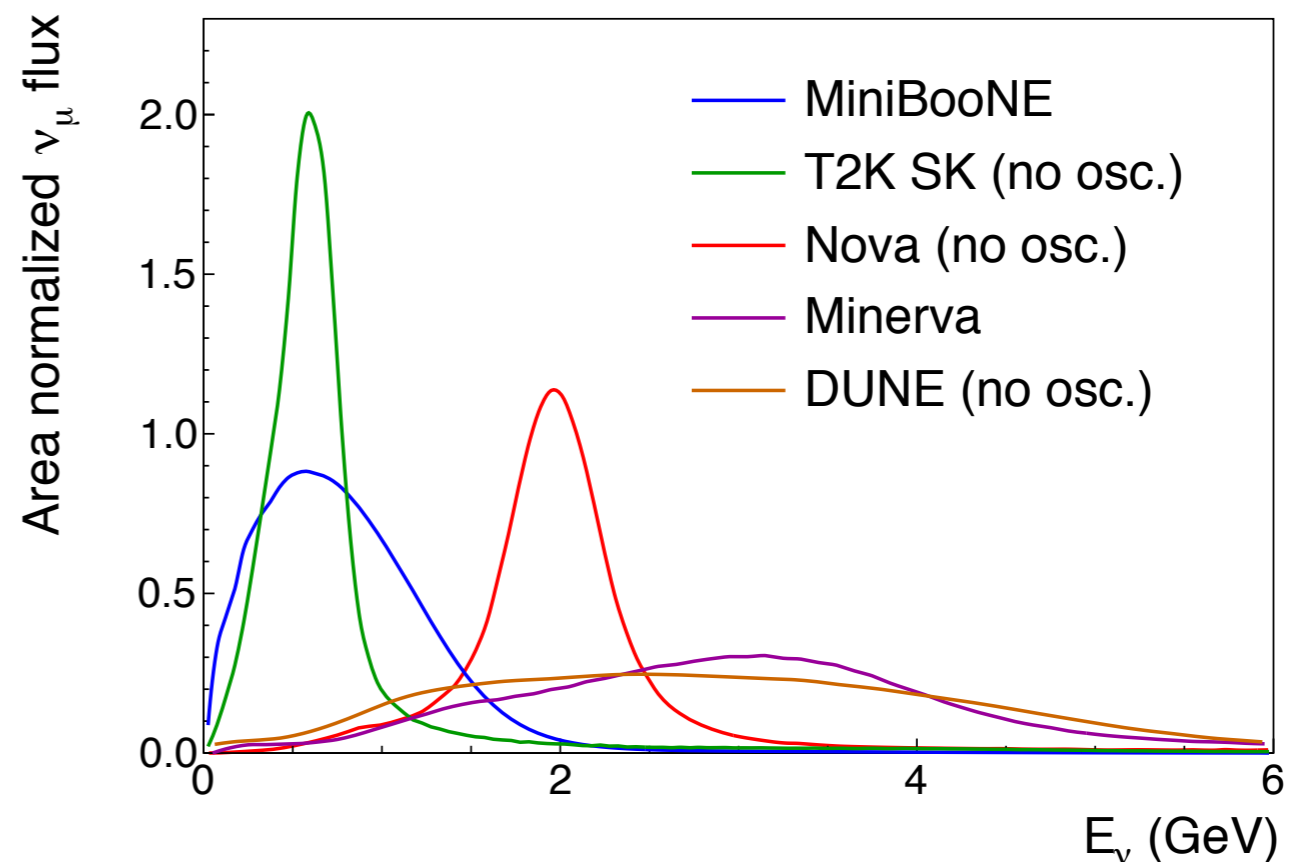
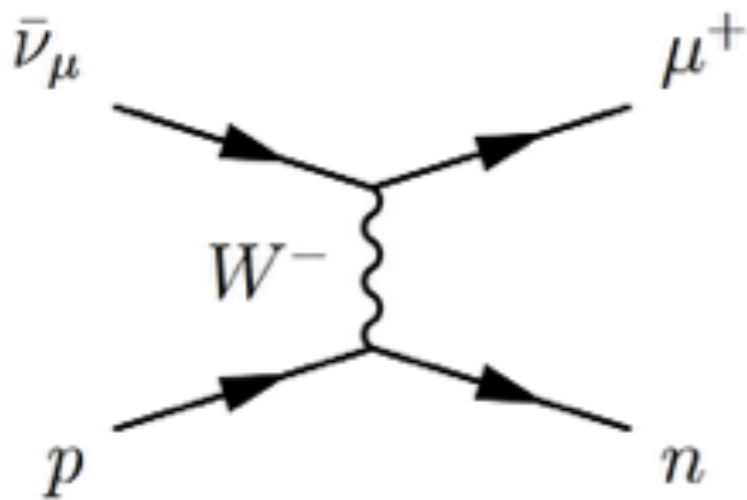
- Electron scattering is used to study nuclear structure
 - Basic interaction between the electron and the target nucleus is known
 - Clean kinematics, the incoming electron energy is known
 - For electron scattering data, flux is known to 1%



- Measurements are performed as a function of the electron energy loss $\omega = \epsilon_1 - \epsilon_2$

Neutrino Scattering

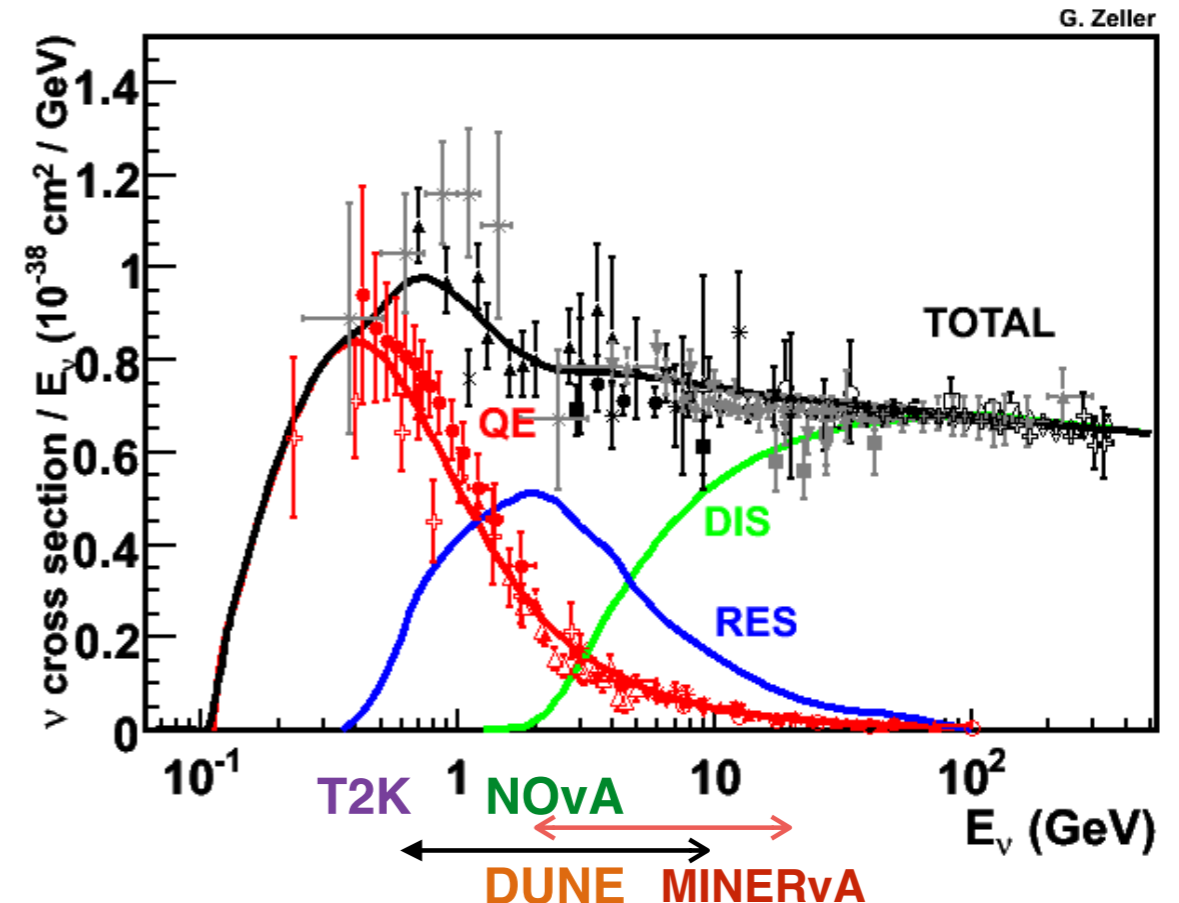
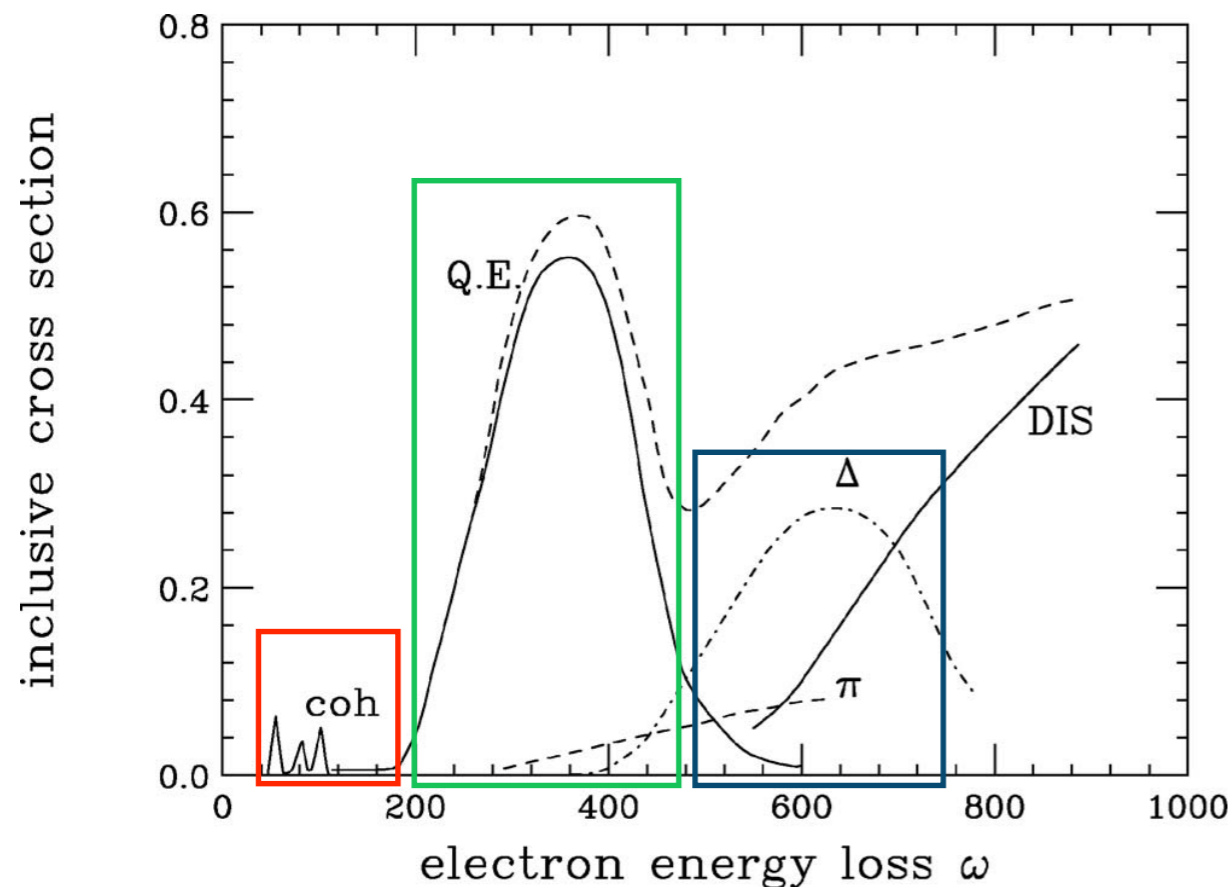
- Flux is known <15%?
- Wide beam neutrino energy spectrums
- We do not know the exact incoming neutrino energy
- We use the final state particles to go back and reconstruct the neutrino energy



- Neutrino measurements are performed using the following variables: T_μ , θ_μ , Q^2 , and E_ν ...

Electron Scattering and Neutrino Scattering

- For electron scattering the electron energy loss is straightforward to measure
- For neutrino scattering the neutrino energy is difficult to measure



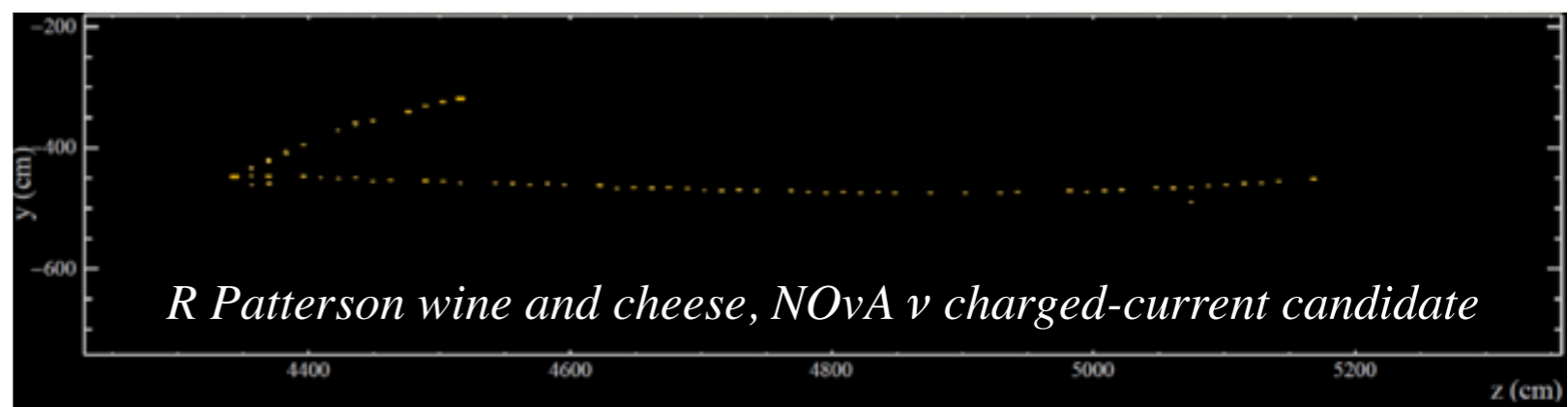
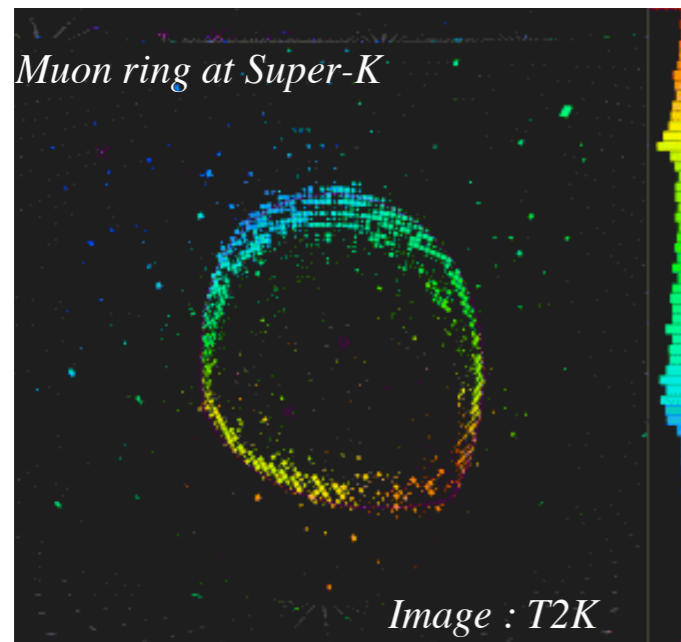
J.A. Formaggio, G. Zeller, Reviews of Modern Physics, 84 (2012)

Neutrino Energy

- Some neutrino experiments use only the muon and others use the proton and muon to reconstruct the neutrino energy
- Cherenkov experiments use muon information to reconstruct the neutrino energy

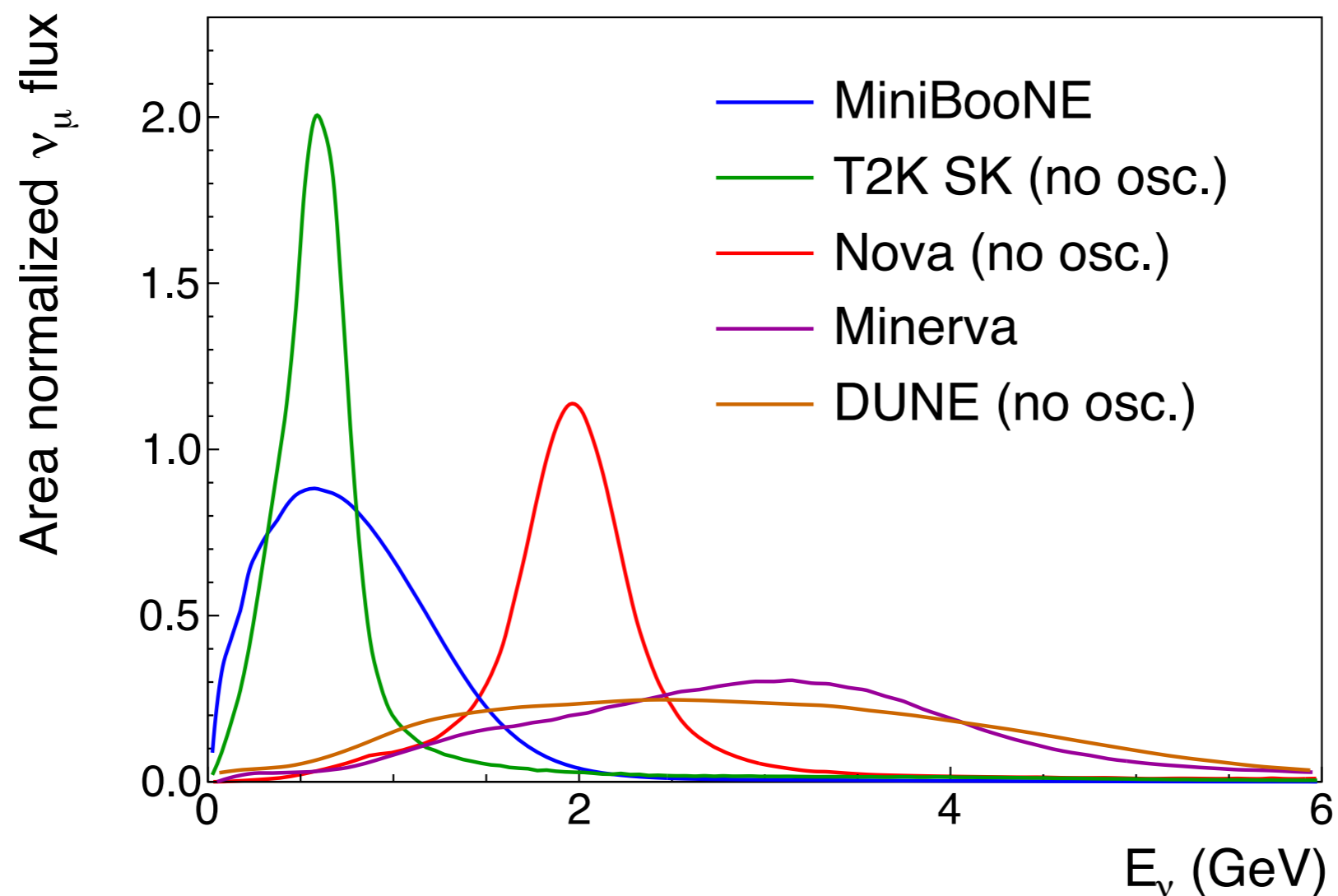
$$E_{QE} = \frac{m_n^2 - (m_p - E_b)^2 - m_\mu^2 + 2(m_p - E_b)E_\mu}{2(m_p - E_b - E_\mu + p_\mu \cos \theta_\mu)}$$

- Fully active experiments reconstruct the energy using: $E_\nu = E_{\text{lepton}} + E_{\text{hadron}}$



Neutrino Oscillation Program

- Near detector is used to extrapolate to far detector
- Accurate knowledge of cross sections are necessary to have precise measurement of oscillation parameters and CP violation



Theoretical and Experimental Developments at INT Workshop

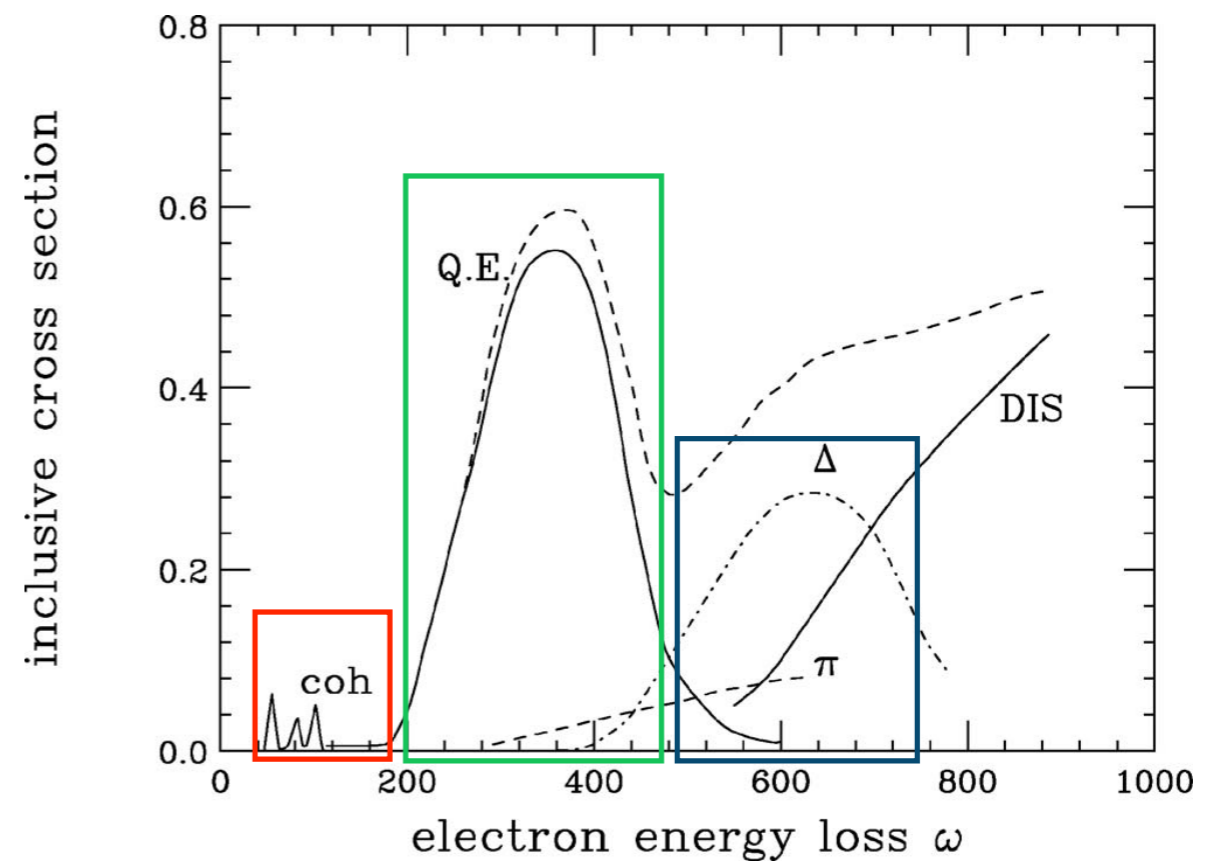
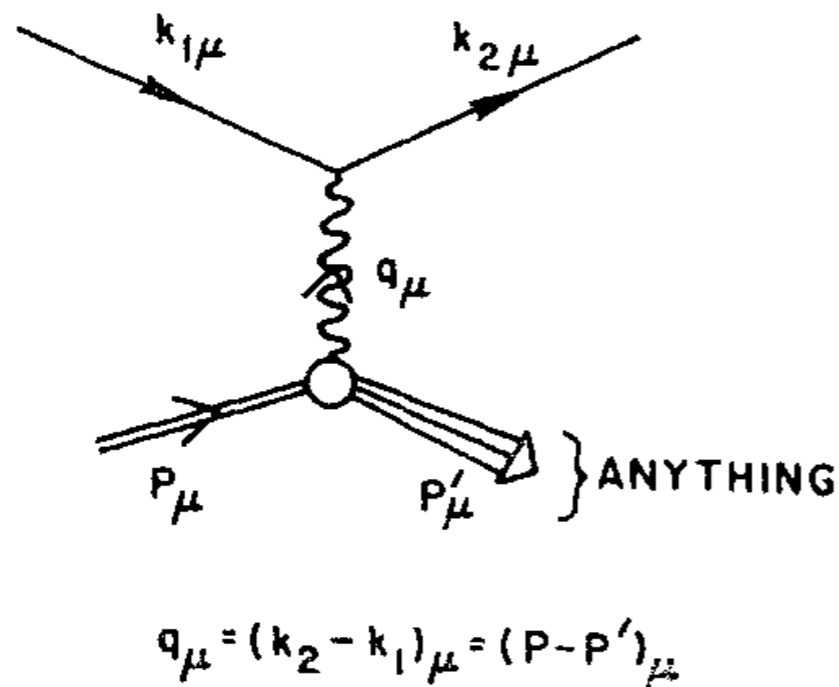
- Several theoretical approaches
- Comparisons to electron scattering data
- Compatibility of neutrino data (Tension 2016 workshop at Pittsburgh)
- Different neutrino event generators
- New measurements from neutrino scattering



Ulrich Mosel reminded us

Theoretical Descriptions and Electron Scattering Data

- Spectral functions
- Super scaling approach SuSA
- Relativistic Mean Field
- Green Function MC



Electron-Nucleus scattering in the Spectral Function approach

Noemi R.

$$\frac{d^2\sigma}{d\Omega_{\mathbf{k}'} dk'_0} = \frac{\alpha^2}{Q^4} \frac{E'_e}{E_e} L_{\mu\nu} W_A^{\mu\nu}$$

The hadron tensor describes the nuclear response

$$W_A^{\mu\nu} = \sum_X \langle 0 | J_A^{\mu\dagger} | X \rangle \langle X | J_A^\nu | 0 \rangle \delta^{(4)}(p_0 + q - p_X)$$

Within the **Impulse Approximation** we factorize the interaction vertex:

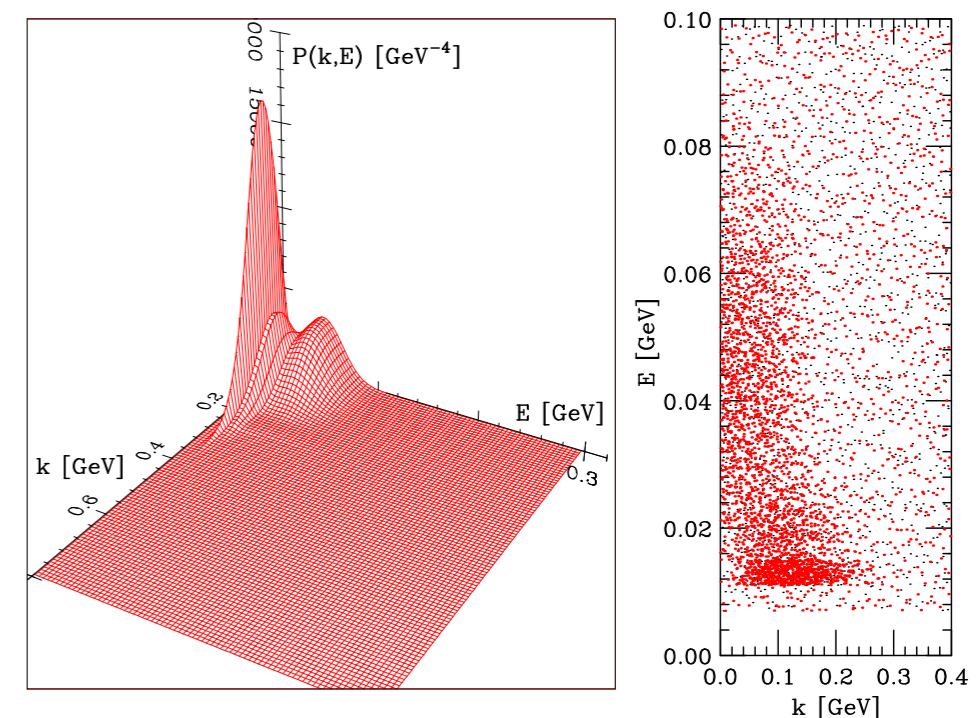
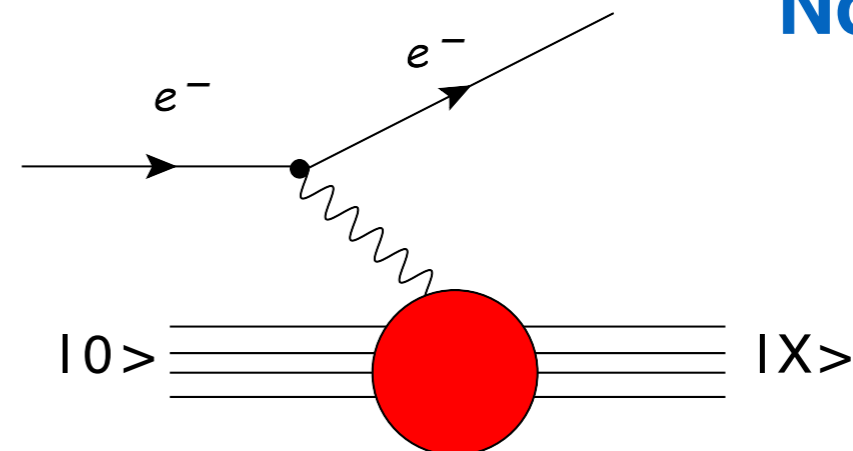
$$J_A^\mu \longrightarrow \sum_i j_i^\mu$$

$$|X\rangle \longrightarrow |x, \mathbf{p}_x\rangle \otimes |R, \mathbf{p}_R\rangle$$

$d\sigma_A$ is written in terms of the fully relativistic cross sections of elementary scattering processes off individual nucleons

$$d\sigma_A = \int dE d^3k d\sigma_N P(k, E)$$

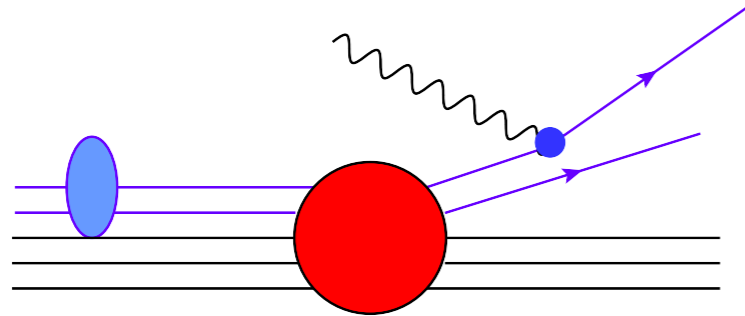
The **Spectral Function** describes the intrinsic properties of the target nucleus. It is computed within Nuclear Many Body Theory



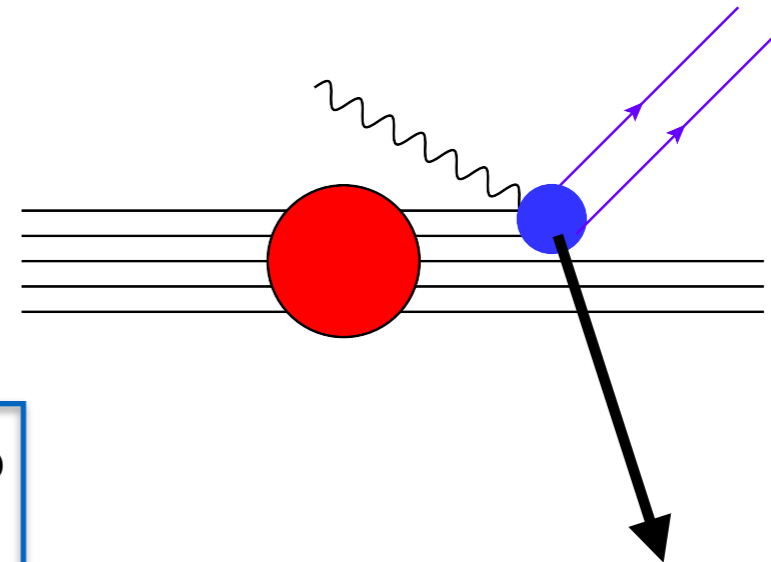
Reaction mechanisms leading to two-nucleon emission

Noemi R.

Initial state correlations (ISC)



Meson exchange currents (MEC)

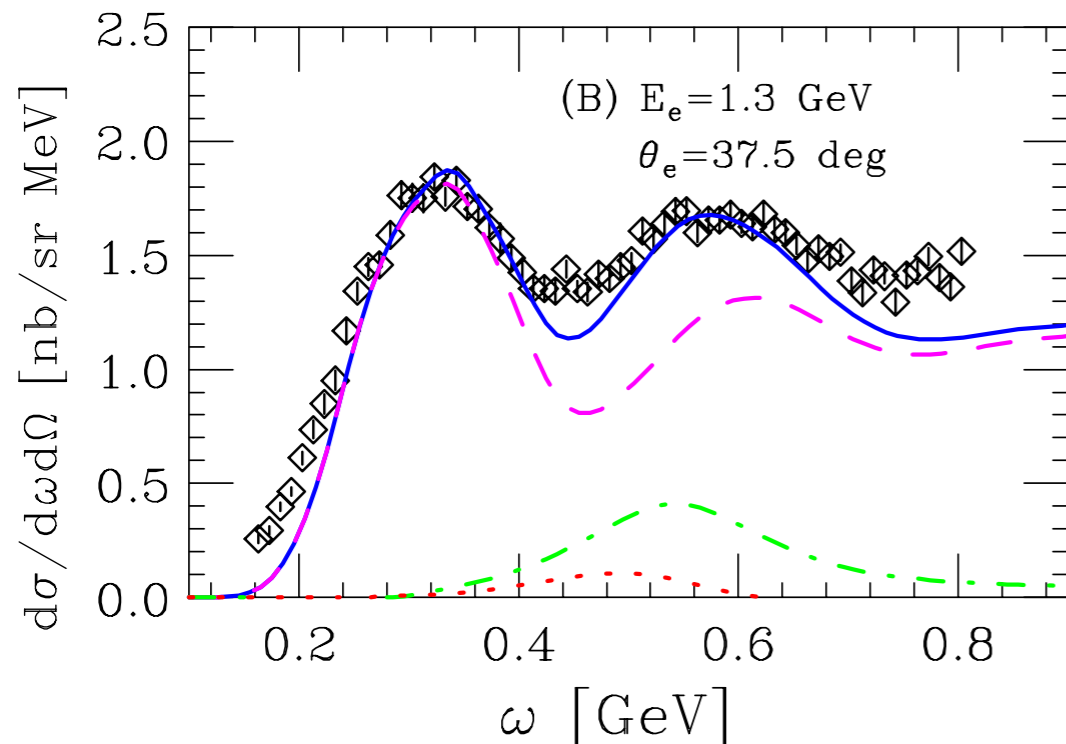


The Spectral Function approach can be generalized to include all these terms in the hadron tensor:

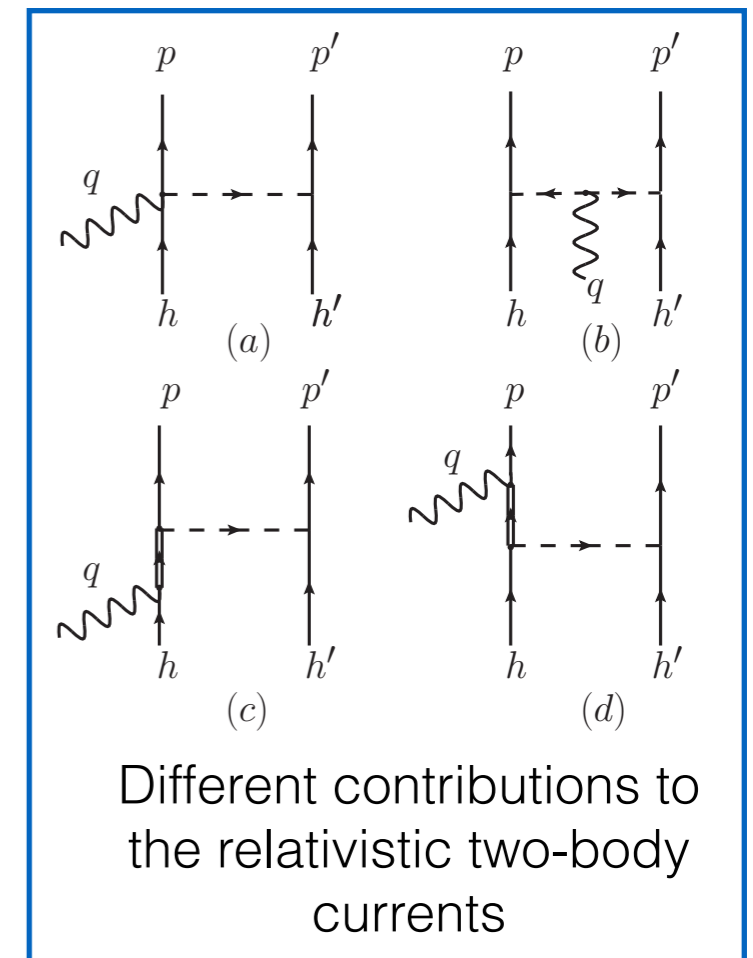
$$W_{2p2h}^{\mu\nu} = W_{2p2h,11}^{\mu\nu} + W_{2p2h,22}^{\mu\nu} + W_{2p2h,12}^{\mu\nu}$$

\downarrow \downarrow \downarrow
 (ISC)² (MEC)² (ISC*MEC)

Final result obtained for electron-Carbon cross section



The blue-line results from the one- and two-body current contributions. Final state interactions are included.



Theoretical description: SuperScaling Approach (SuSA)

G. Megias

- Based on the superscaling function extracted from QE electron scattering data.
- Scaling:** The response of a many-body system *scales* when it can be described in terms of a particular combination of two variables, called **scaling variable** $\psi(\omega, q)$. In lepton-nucleus scattering, nuclear effects can be analyzed through a **Scaling Function** $f(\psi)$ constructed from the ratio between the QE cross section and the proper single-nucleon one.
- The scaling function is related to the momentum distribution of the nucleons and embodies all the nuclear dependence of the model.

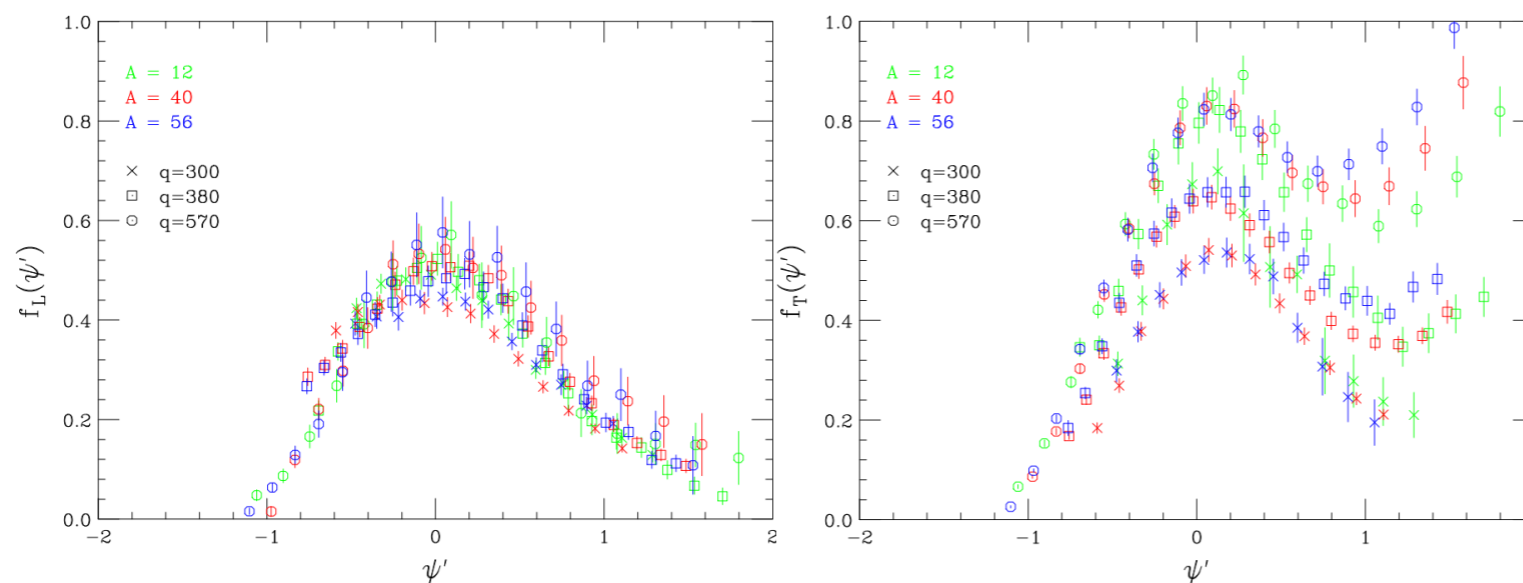
$$f(\psi) \equiv f(q, \omega) \sim \frac{\sigma_{QE}(\text{nuclear effects})}{\sigma_{\text{single nucleon}}(\text{no nuclear effects})} \quad ; \quad \psi\text{-scaling variable}$$

In inclusive QE scattering we can observe:

- ★ Scaling of 1st kind (independence on q)
- ★ Scaling of 2nd kind (independence on Z)



SuperScaling



Scaling violations in the T channel ⇒ 2p-2h MEC, correlations

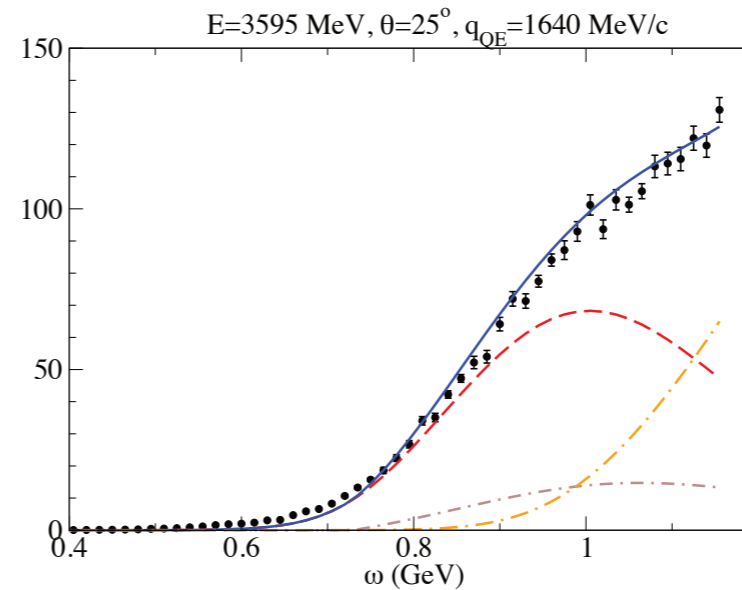
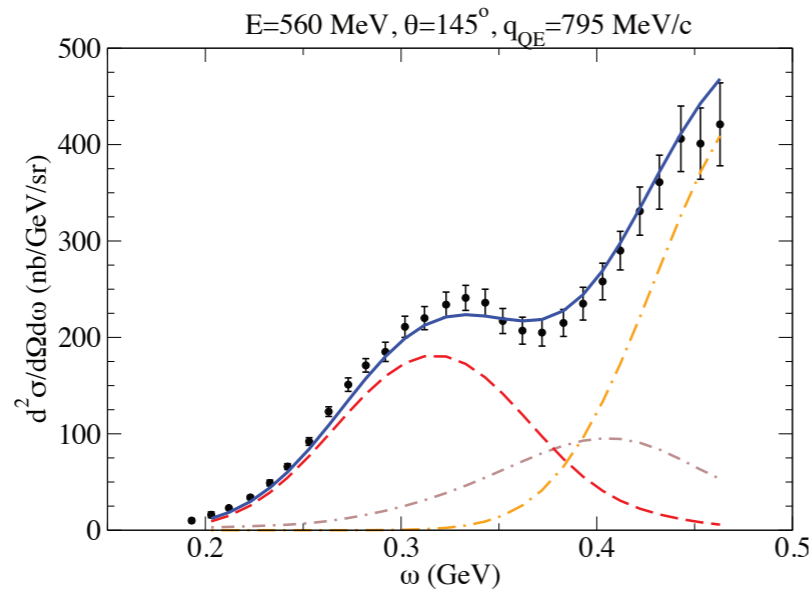
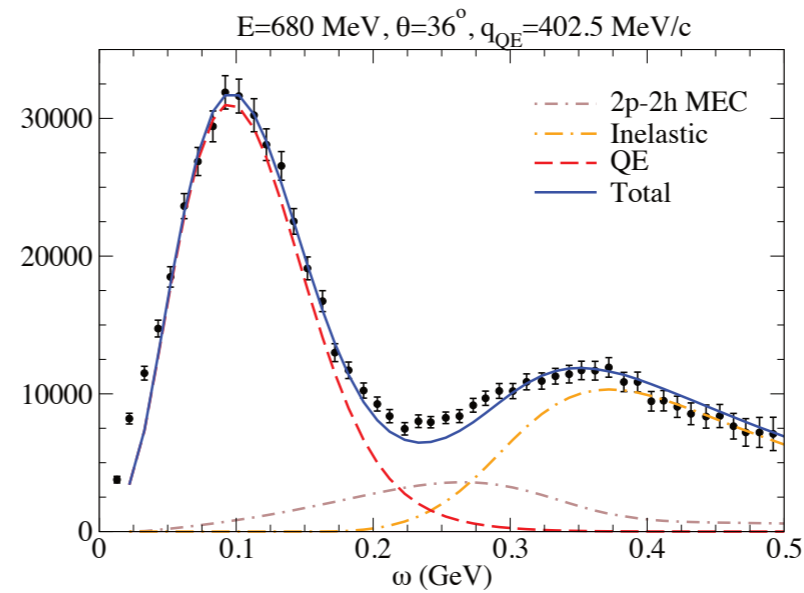
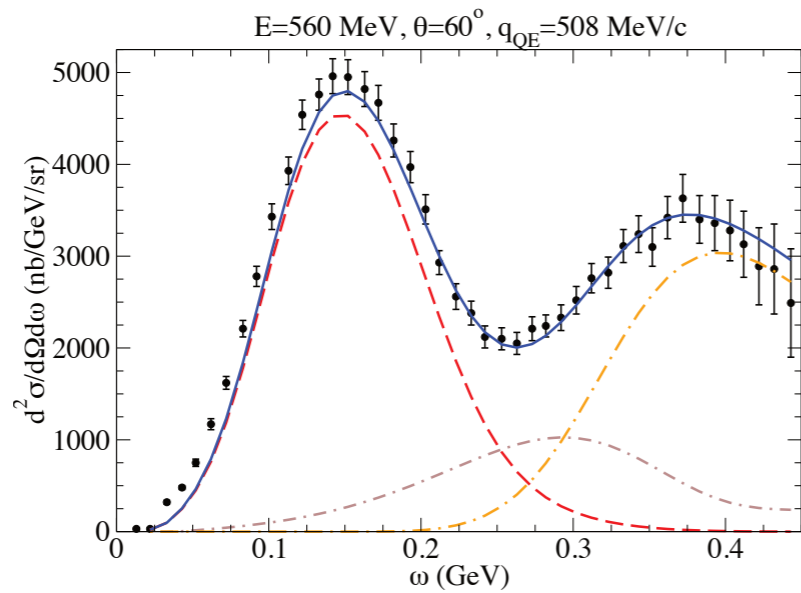
G.D. Megias (University of Seville)

Inclusive (e,e') reactions within the SuSAv2-MEC approach

Comparisons with Electron Scattering Data

G. Megias

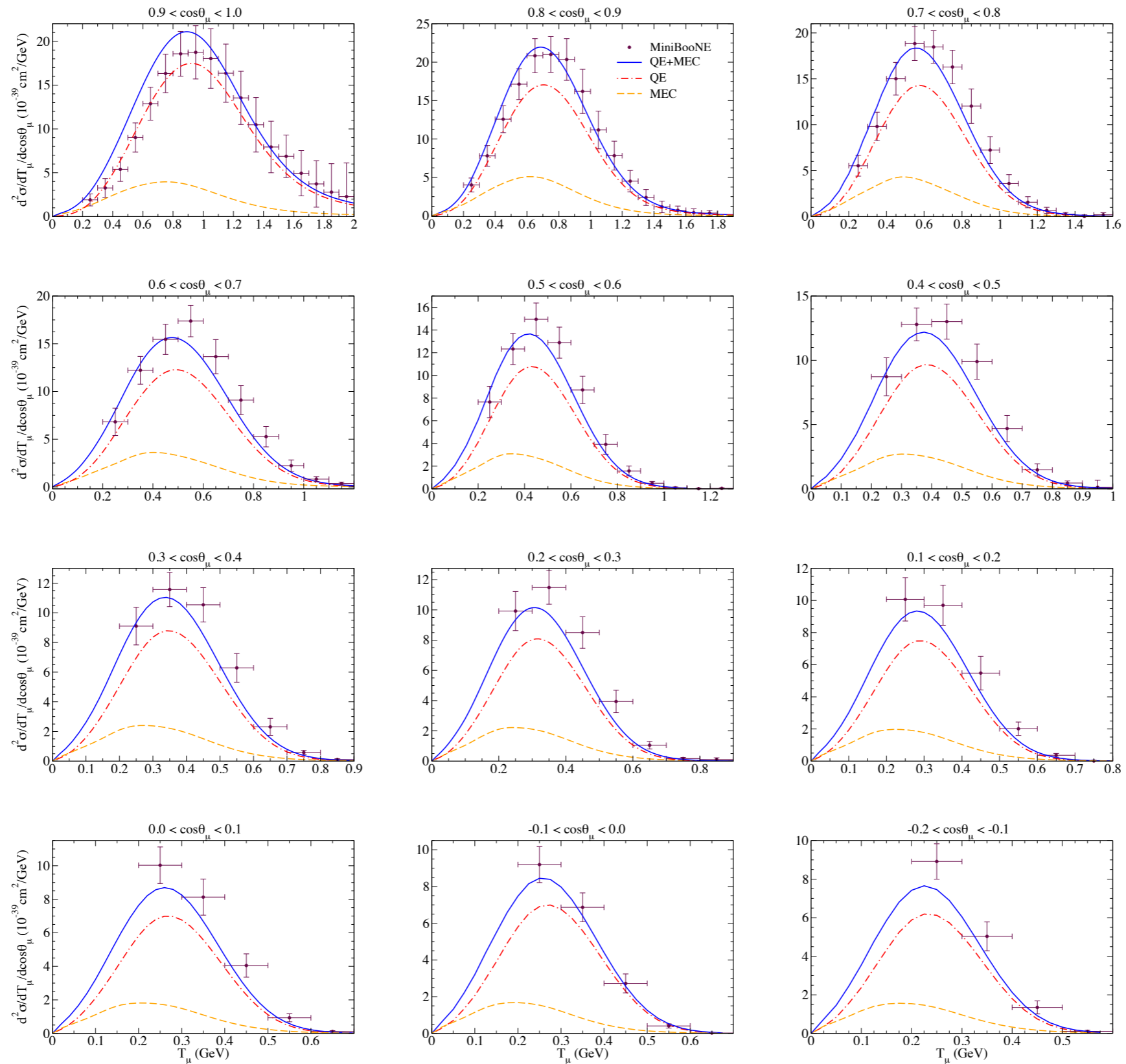
Inclusive $^{12}\text{C}(e, e')$ cross sections *PRD 94, 013012 (2016)*



G.D. Megias (University of Seville)

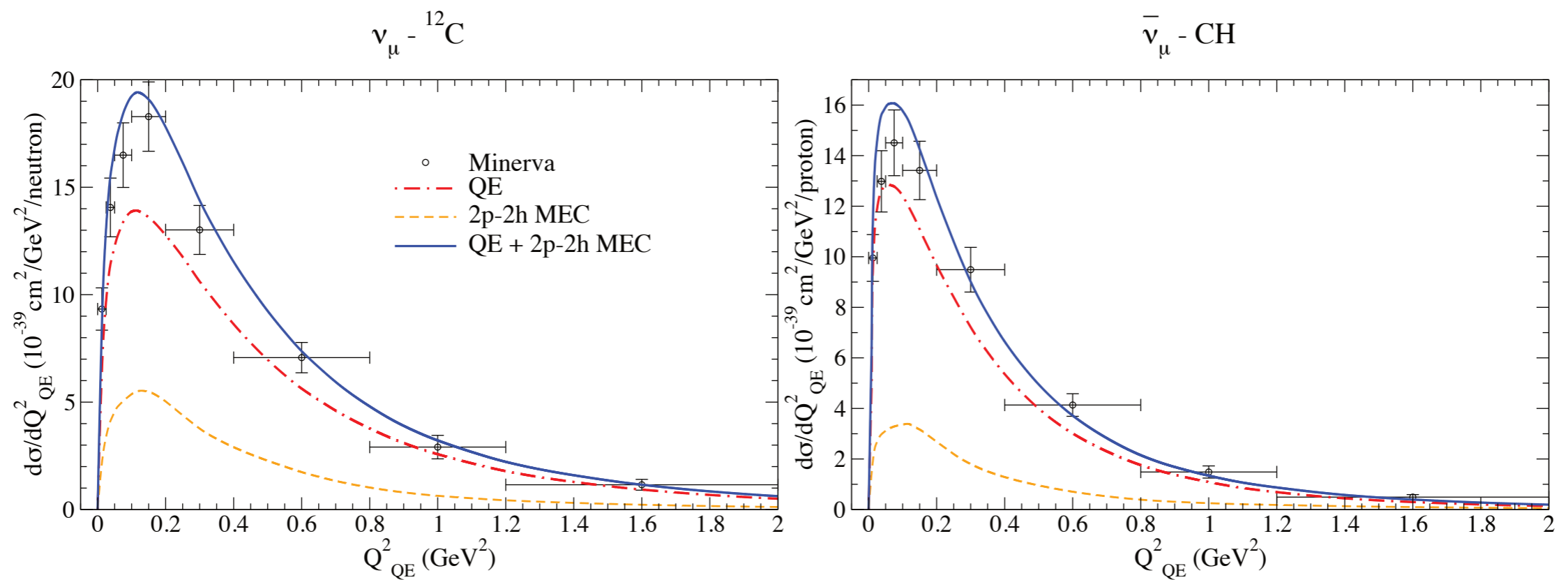
Inclusive (e, e') reactions within the SuSAv2-MEC approach

Muon Neutrino CCQE (MiniBooNE)

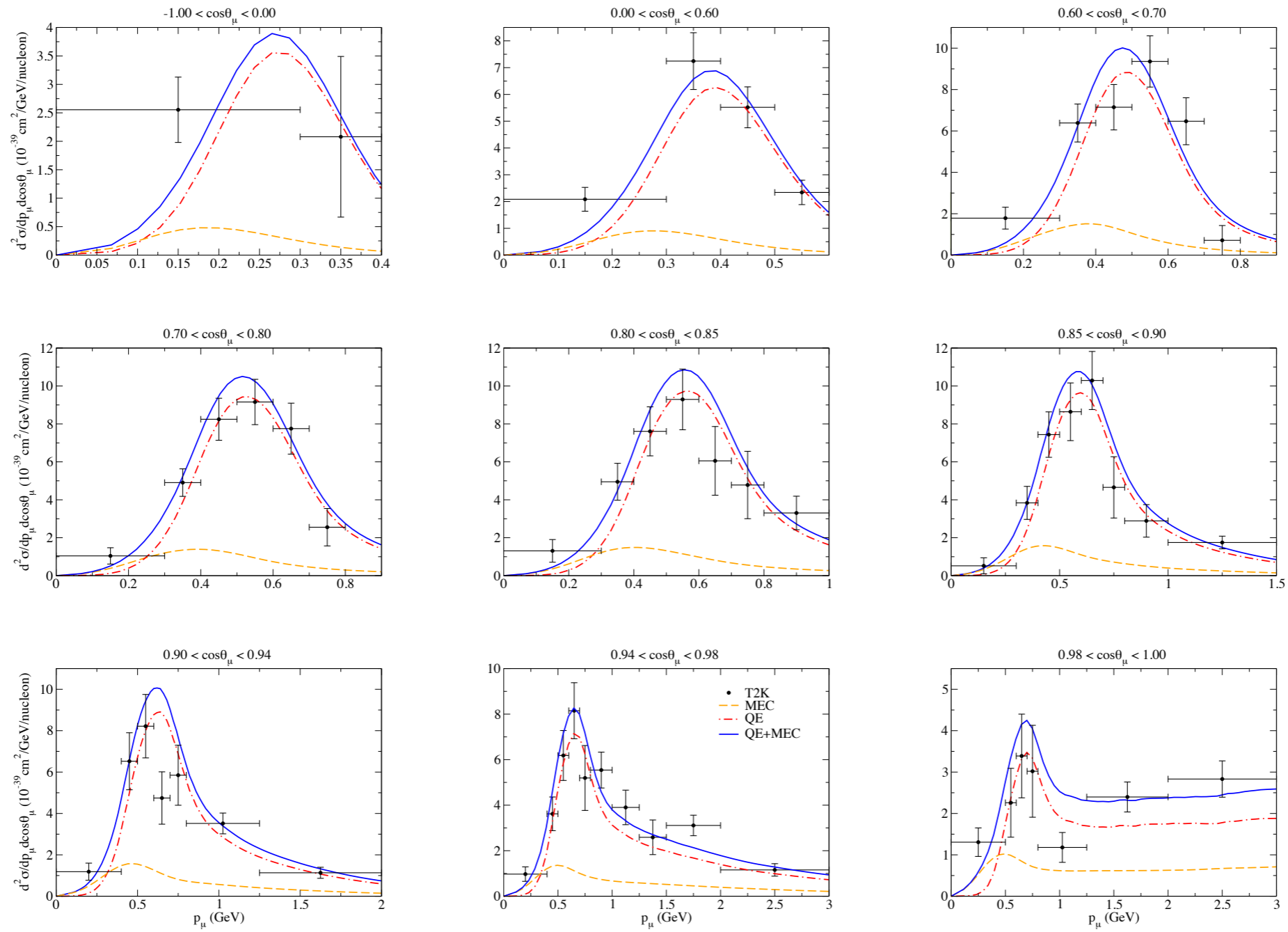


Muon Neutrino Data CCQE (MINERvA)

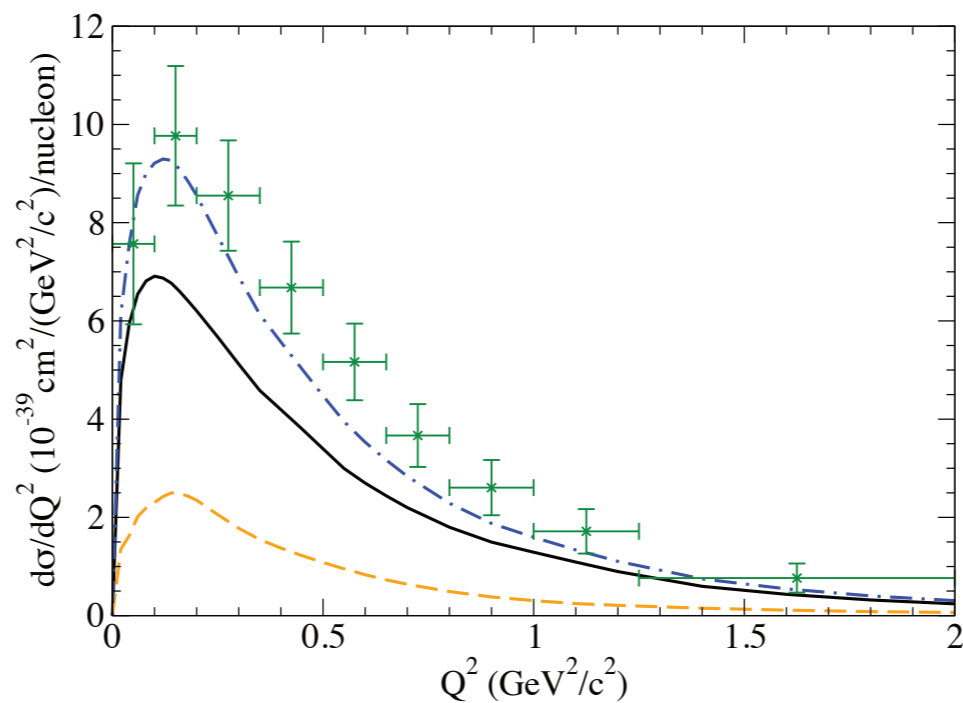
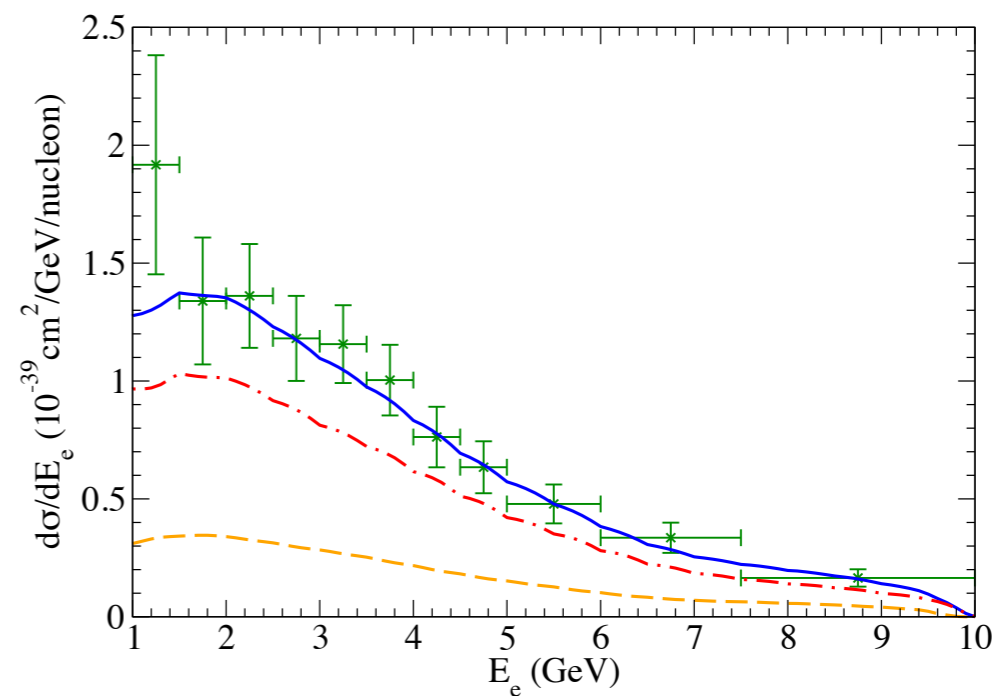
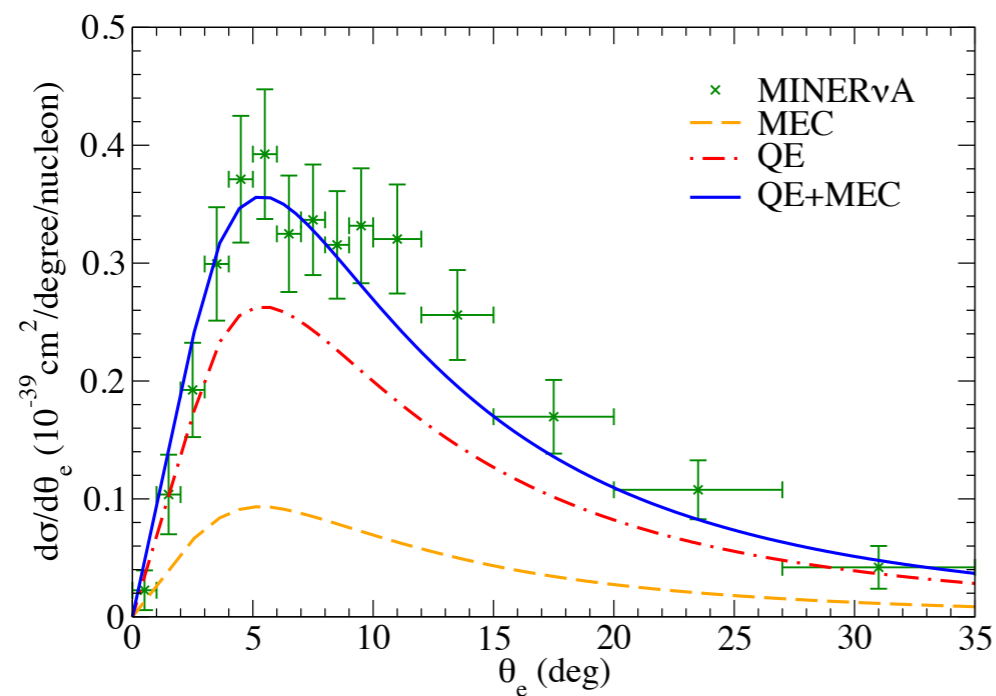
Megias *et al.*, PRD 94, 093004 (2016)



Muon Neutrino CCQE (T2K)

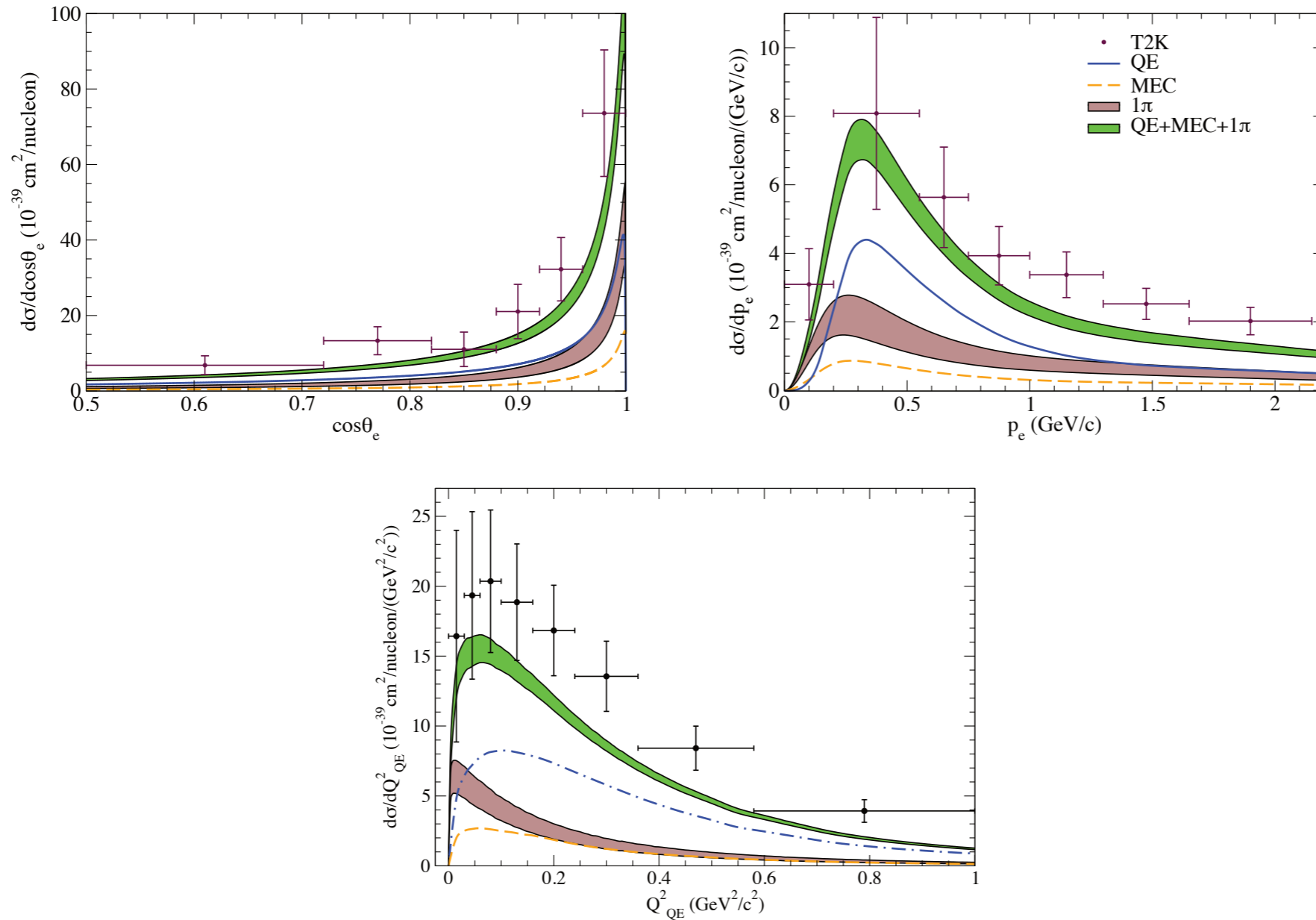


Electron Neutrino Data CCQE-like (MINERvA)



Electron Neutrino Inclusive (T2K)

Megias *et al.*, PRD 94, 093004 (2016)



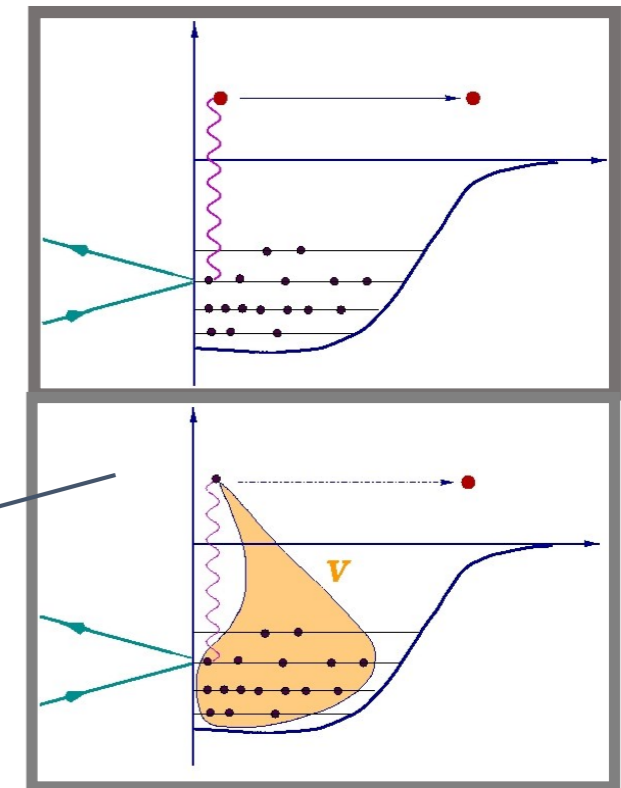
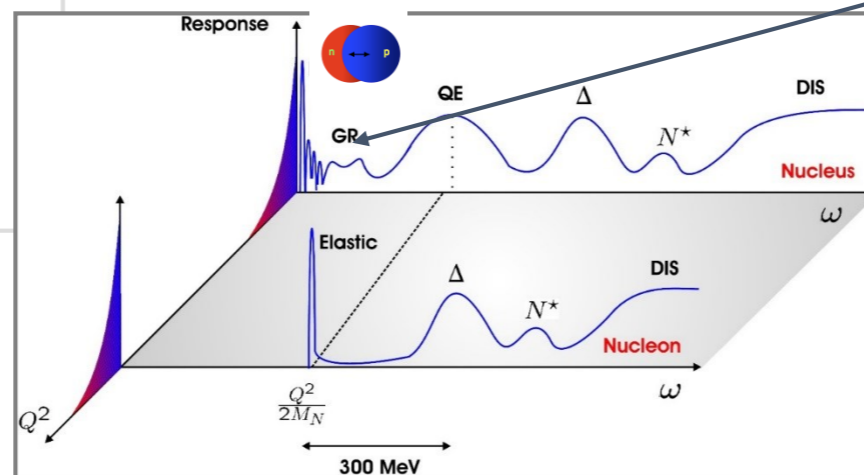
Correlations in QE-like Neutrino-Nucleus Scattering

Cross section calculations

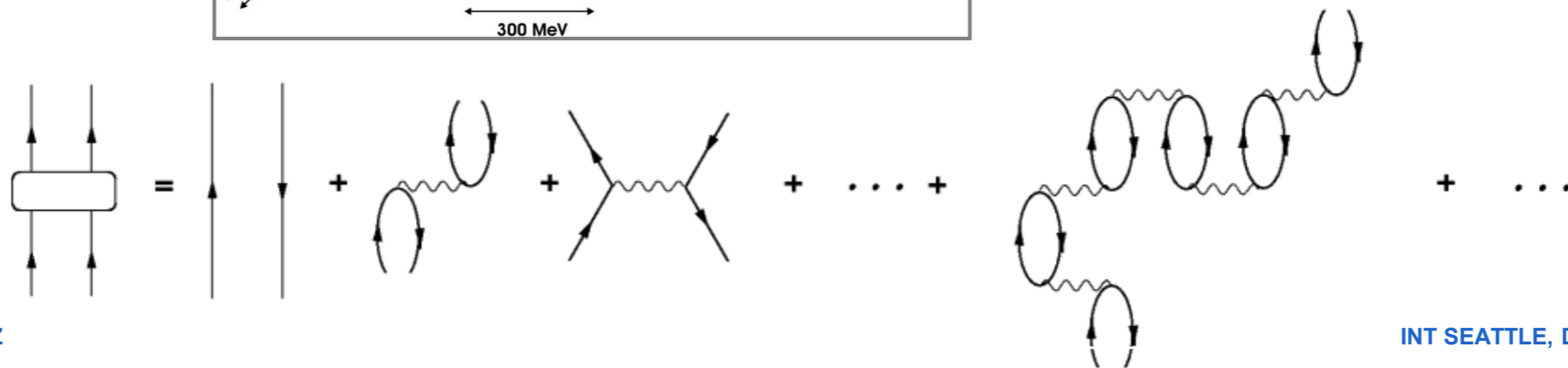
- Starting point : mean-field nucleus with Hartree-Fock single-particle wave functions
- Skyrme SkE2 force used to build the potential
- Pauli blocking
- binding

Long-range correlations : Continuum RPA

- Green's function approach
- Skyrme SkE2 residual interaction
- self-consistent calculations



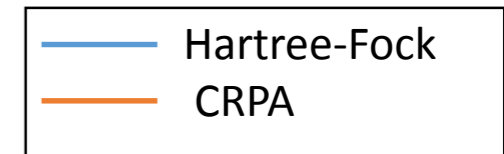
$$|\Psi_{RPA}\rangle = \sum_c \left\{ X_{(\Psi,C)} |ph^{-1}\rangle - Y_{(\Psi,C)} |hp^{-1}\rangle \right\}$$



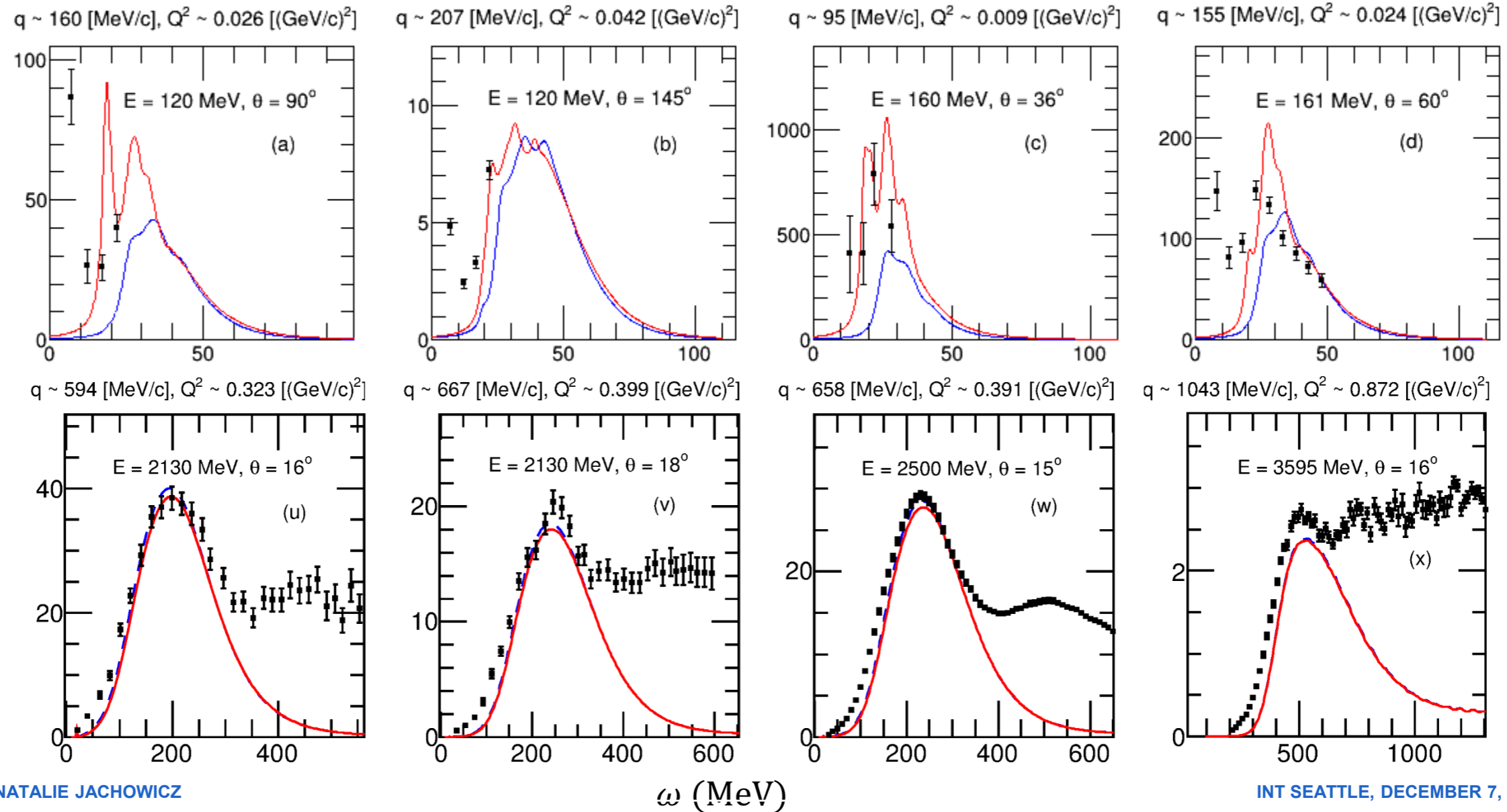
Correlations in QE-like Neutrino-Nucleus Scattering

CRPA : Comparison with electron scattering data

$^{12}\text{C}(e, e')$



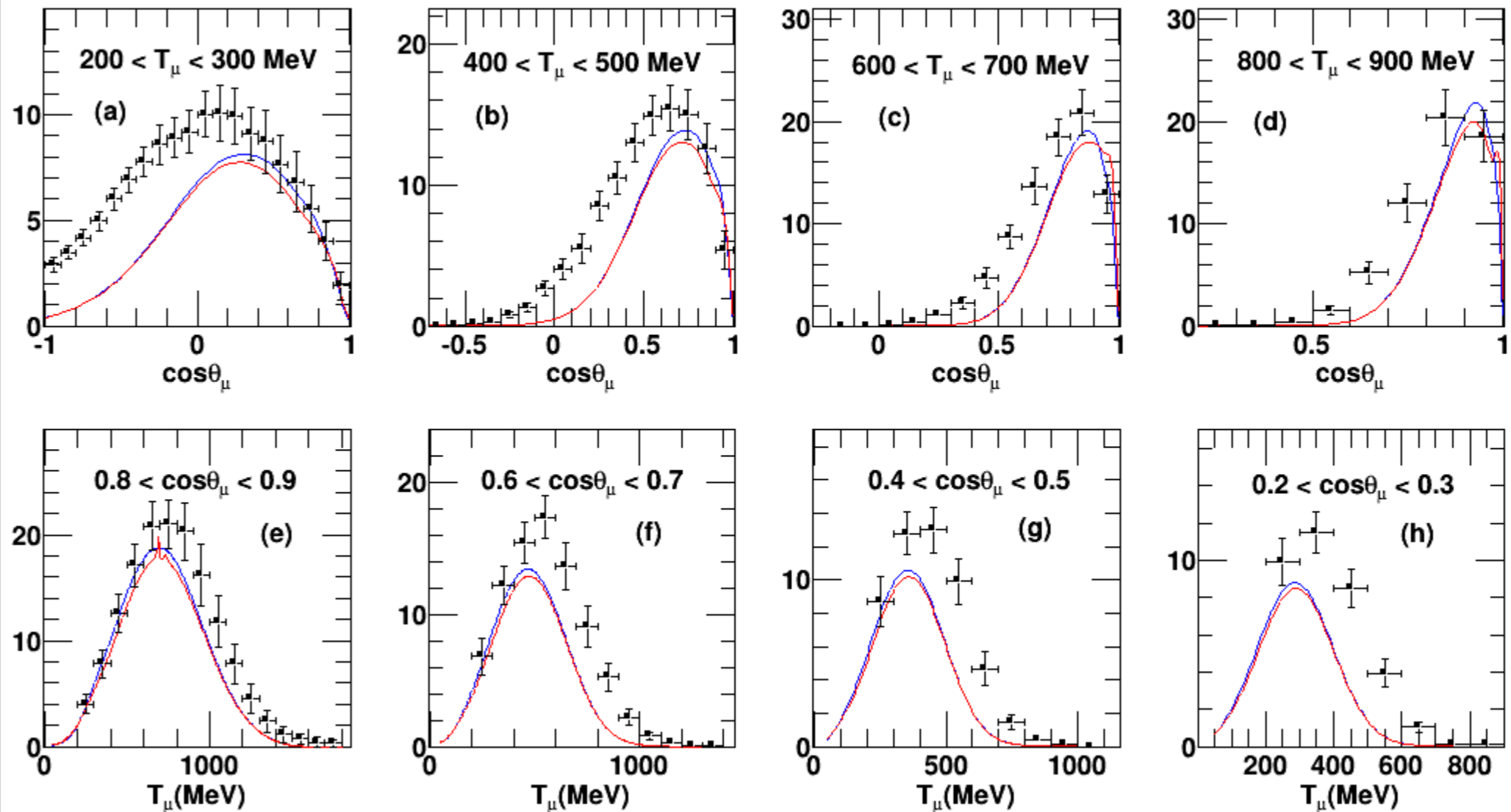
$d^2\sigma/d\omega d\Omega(\text{nb/MeV sr})$



Comparisons with MiniBooNE Data

MiniBooNE ν_μ

- Satisfactory general agreement
- Good agreement for forward scattering
- Missing strength for low T_μ , backward scattering can be attributed to multinucleon effects



Relativistic Mean Field Approach

Nucleon Wave Functions \Rightarrow *Solutions of Dirac equation with phenomenological relativistic potentials (scalar and vector terms):*

- **Ψ_B : Bound nucleon wave function** \Rightarrow
Relativistic Mean Field (RMF) Approach

Local potentials obtained from a Lagrangian fitted to properties of nuclear matter, radii and nuclear masses.

The non-relativistic reduction of the RMF formalism leads to a Schrödinger-like equation but with presence of non-local terms.

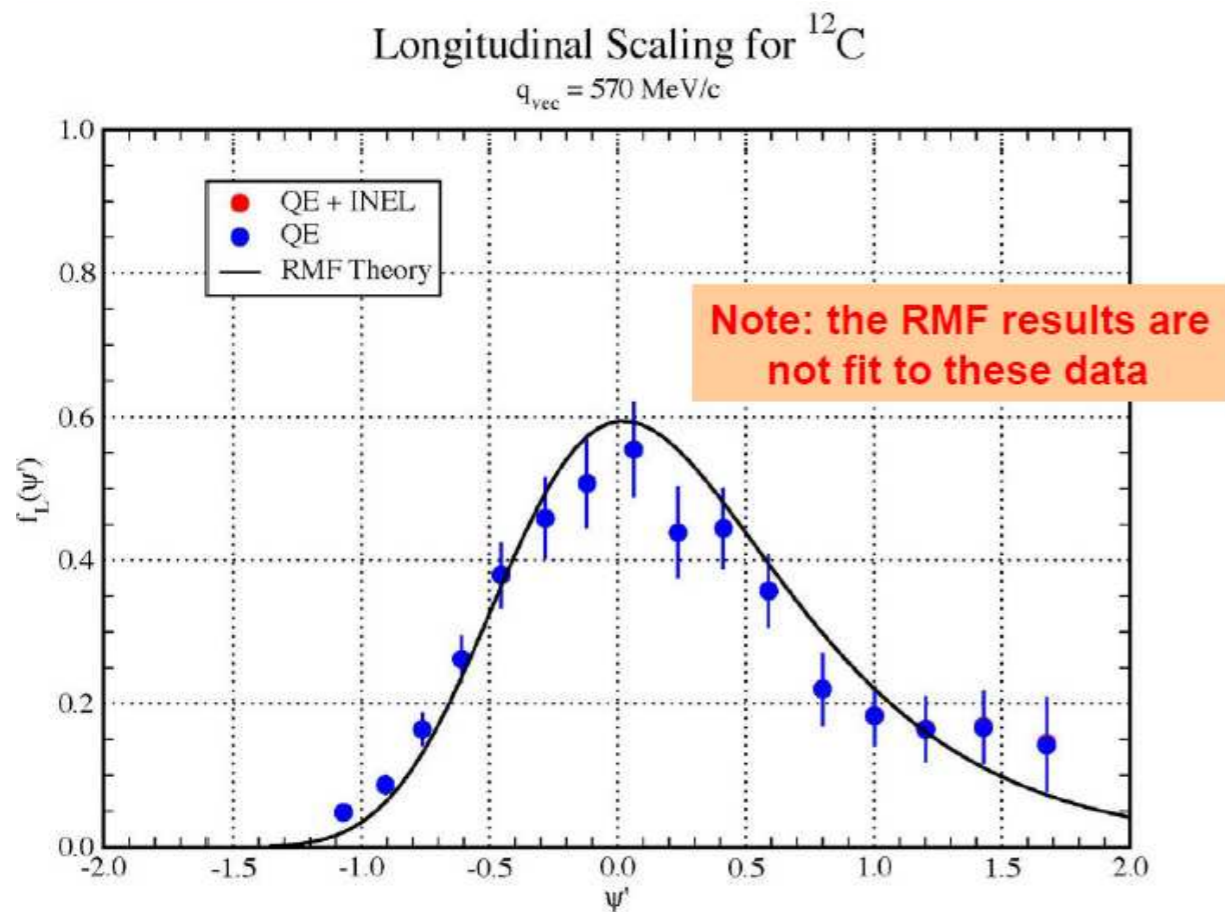
$$\left[-\frac{\nabla^2}{2m_N} - V_{\text{DEB}} \right] \phi_{\text{nr}}(\mathbf{r}) = E_{\text{nr}} \phi_{\text{nr}}(\mathbf{r}); \quad \Psi_{up}(\mathbf{r}) = K(r) \phi_{\text{nr}}(\mathbf{r})$$

$K(r) \sim 0.8$ in the nuclear interior going to unity asymptotically

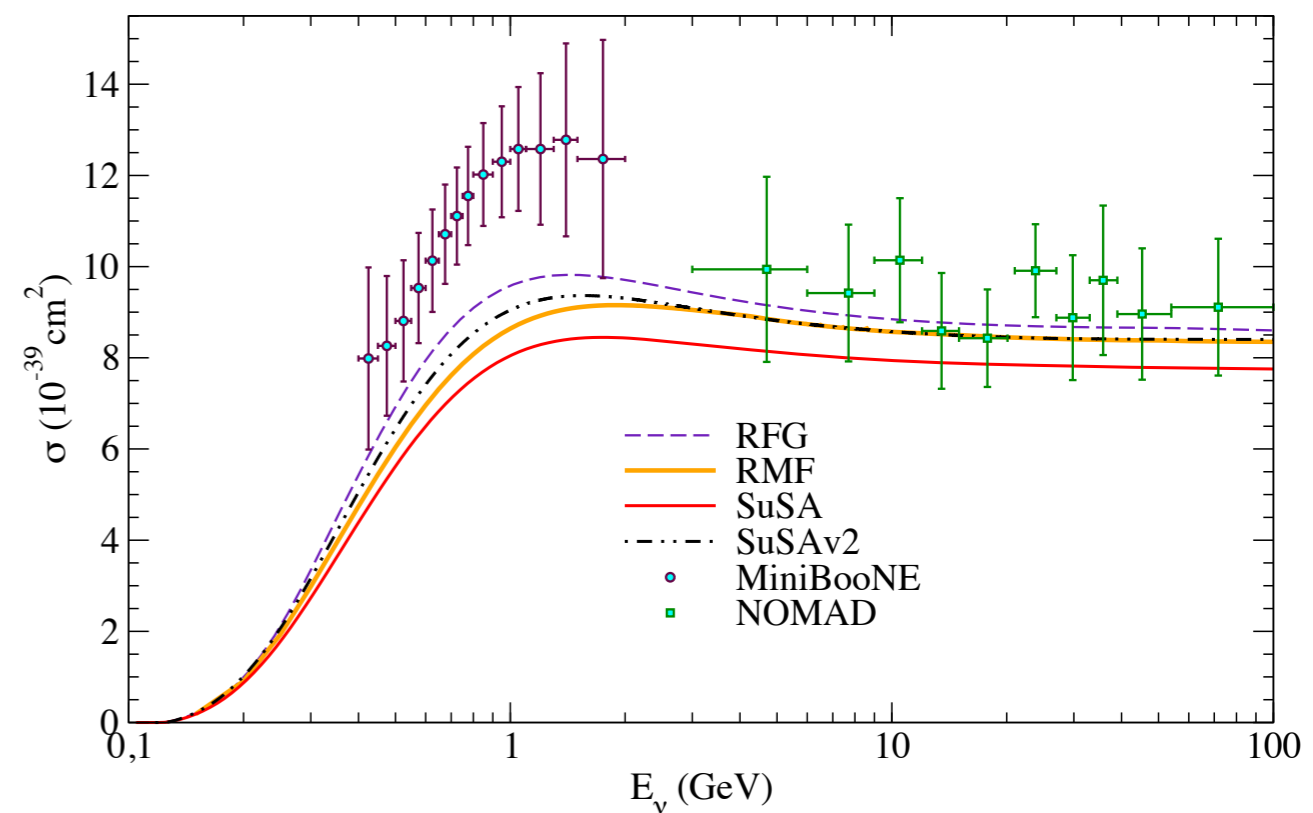
- **Ψ_F : Ejected nucleon wave function** \Rightarrow
Dependence with final state interactions (FSI)

Comparisons of RMF and Data

Electron Scattering data



CCQE Neutrino Scattering data



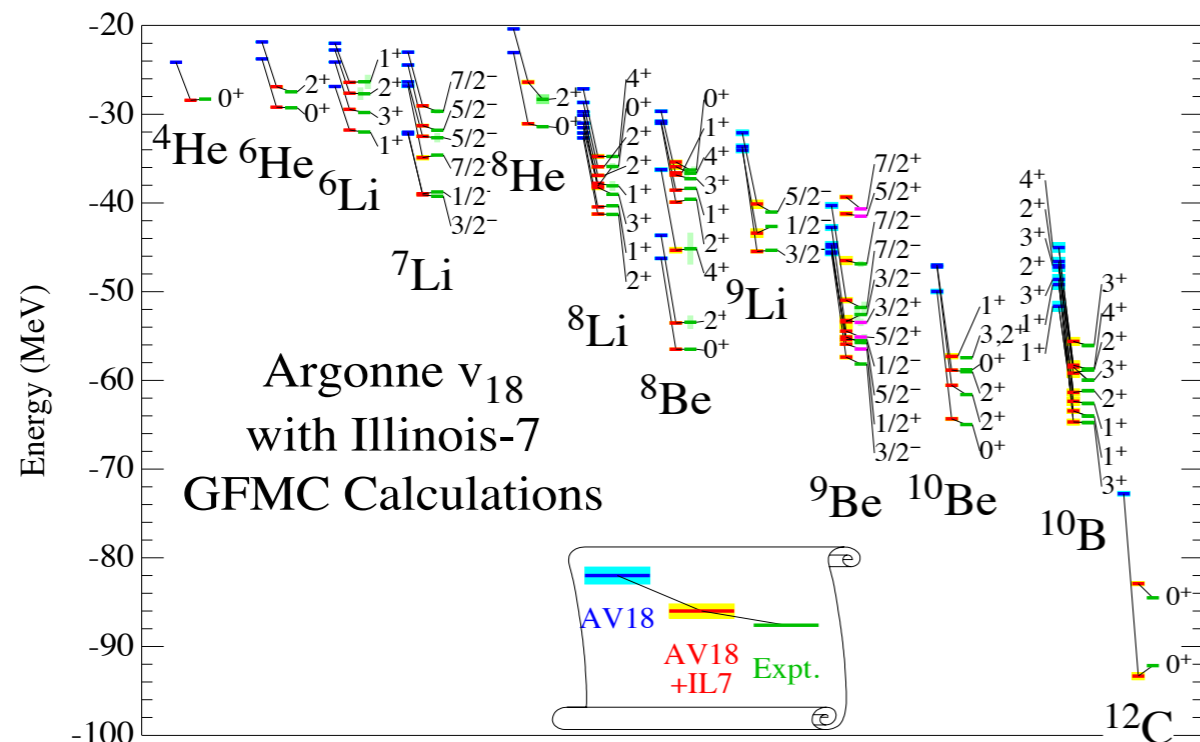
- The Green' function Monte Carlo approach is based on a realistic nuclear Hamiltonian and consistent meson exchange current

$$H = \sum_i \frac{\mathbf{p}_i^2}{2m} + \sum_{i<j} v_{ij} + \sum_{i<j<k} V_{ijk} + \dots \quad \nabla \cdot \mathbf{J}_{\text{EM}} + i[H, J_{\text{EM}}^0] = 0$$

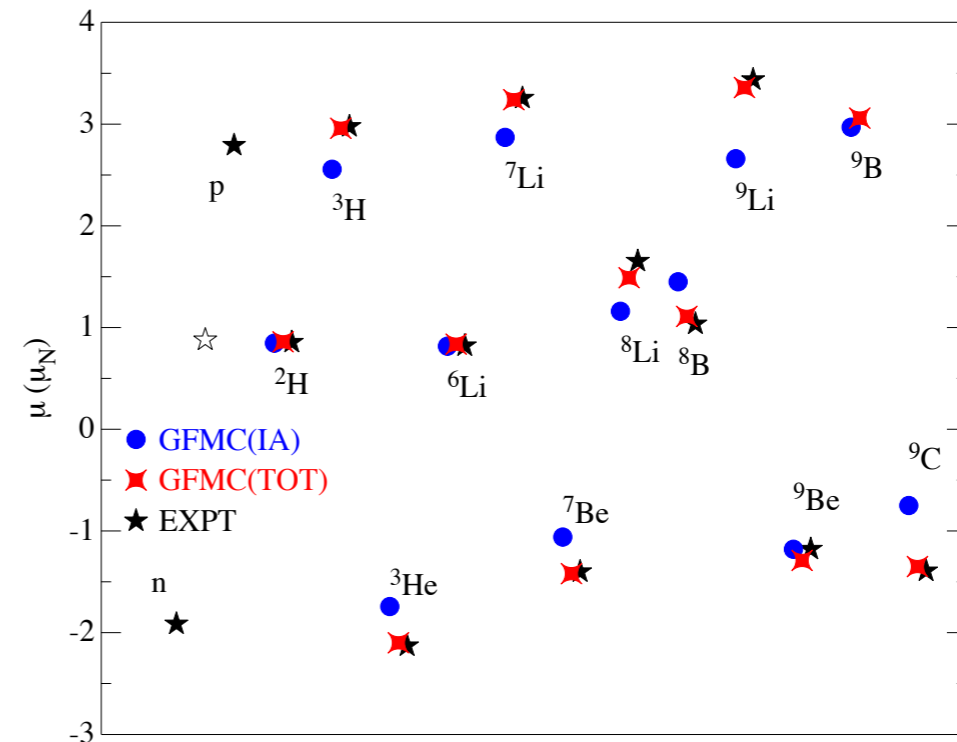
- The Schrödinger equation is solved by means of imaginary-time diffusion techniques

$$\lim_{\tau \rightarrow \infty} e^{-(H-E_0)\tau} |\Psi_T\rangle = \lim_{\tau \rightarrow \infty} \sum_n c_n e^{-(E_n-E_0)\tau} |\Psi_n\rangle = c_0 |\Psi_0\rangle$$

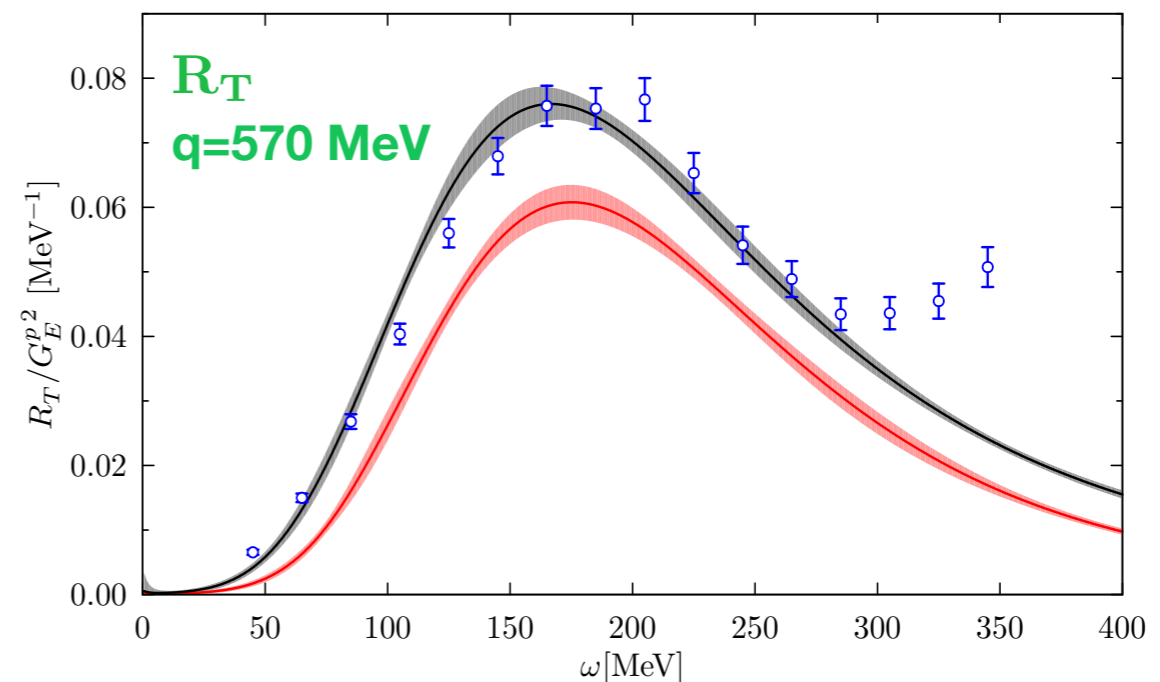
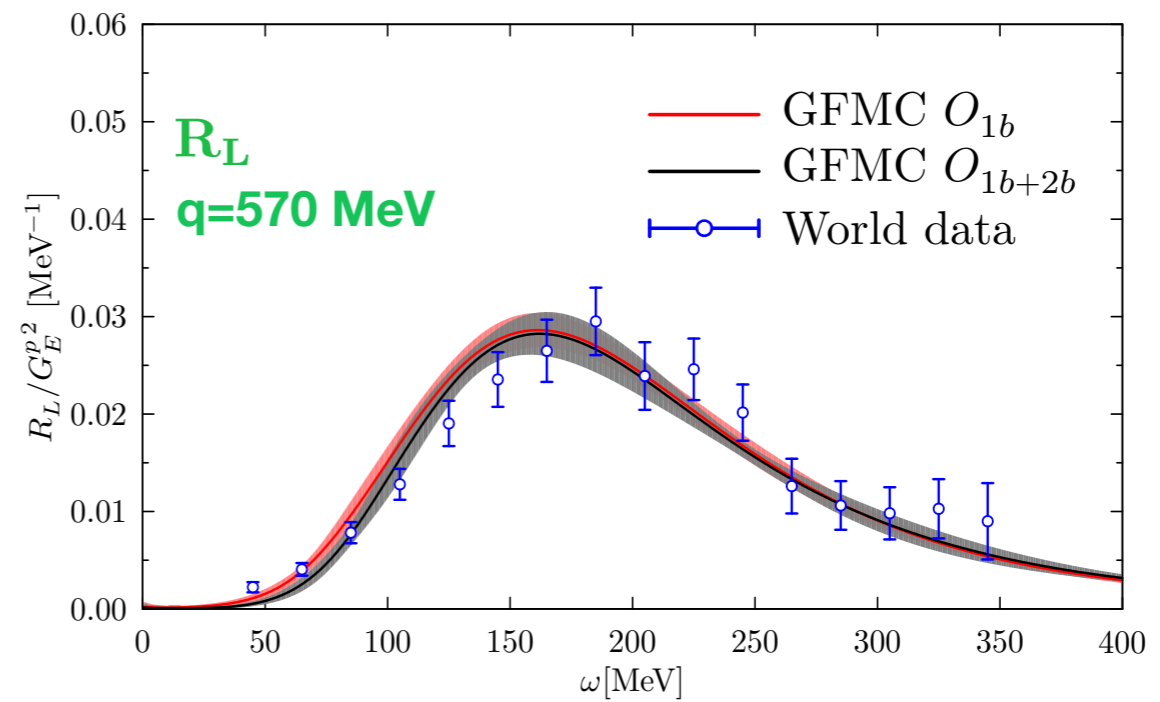
Excellent fit of the spectrum of light nuclei



MEC are essential for magnetic moments



- We performed the first ab-initio calculation of the electromagnetic response for ^{12}C
- Small contribution from two-body currents to the longitudinal response functions.
- Excellent agreement with experiments without modifying the proton electric form factor
- Sizable contribution from two-body currents to the transverse response functions in the region of the quasi elastic peak
- Relativistic effects are investigated through a comparison with the spectral function approach
- We are now computing the axial responses
- Extension to nuclei larger than ^{12}C non trivial
- Theoretical error accurately estimated



Neutrino Scattering Data

Neutrino Scattering Measurements

- This past summer, neutrino experimentalists got together in an exclusive workshop to understand the cross sections data sets from different experiments, mainly MiniBooNE, MINERvA and T2K
 - Discussions were concentrated to understand: CCQE and Resonance

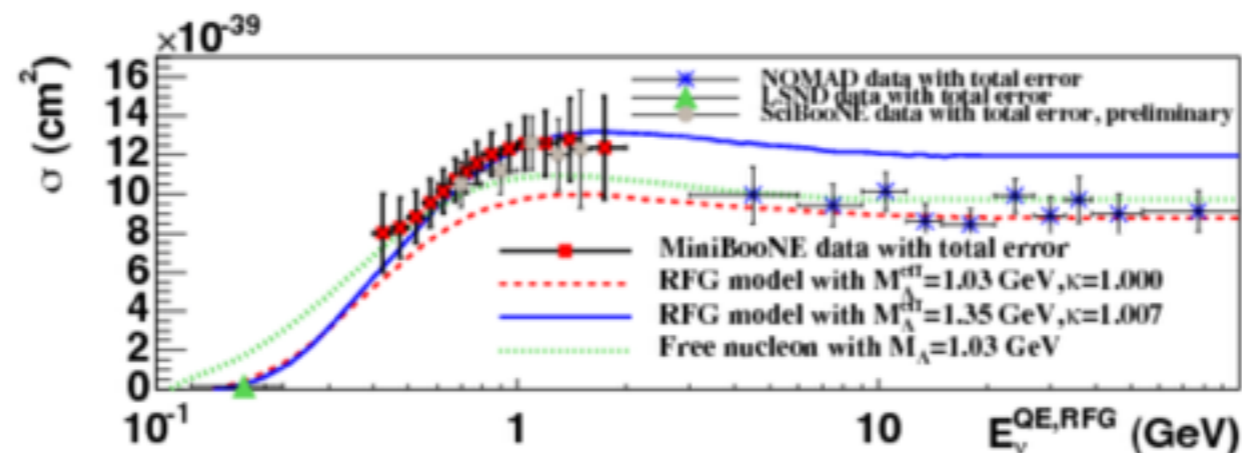
Neutrino Cross-section Data Tensions Workshop

last edited by  Kendall Mahn 4 months, 3 weeks ago

 Page history

Exploring Tensions in Neutrino-nucleus Cross Section Data
July 25–31, 2016
University of Pittsburgh, Dept. of Physics and Astronomy
sponsored by PittPACC

Neutrino Cross-section Data Tensions Workshop



<http://nugevxsectensions.pbworks.com/w/page/107587302/Neutrino%20Cross-section%20Data%20Tensions%20Workshop>

Neutrino Scattering Measurements

- Concentrating on small data set of available measurements

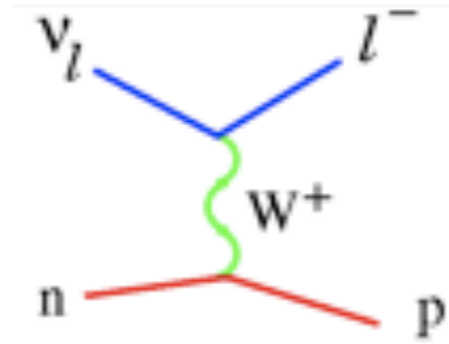
First generation:

- CC0 π with **muon only**

MiniBooNE on CH

MINERvA on CH

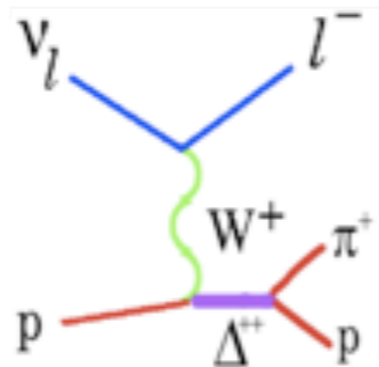
T2K on CH and water (new!)



- CC1 π with **muon + pion**

MINERvA on CH

T2K on CH and water



Second generation:

- CC0 π with **muon + proton(s)**

ArgoNeut on Ar

T2K on CH: arriving soon...

- **muon + hadronic energy / vertex energy**

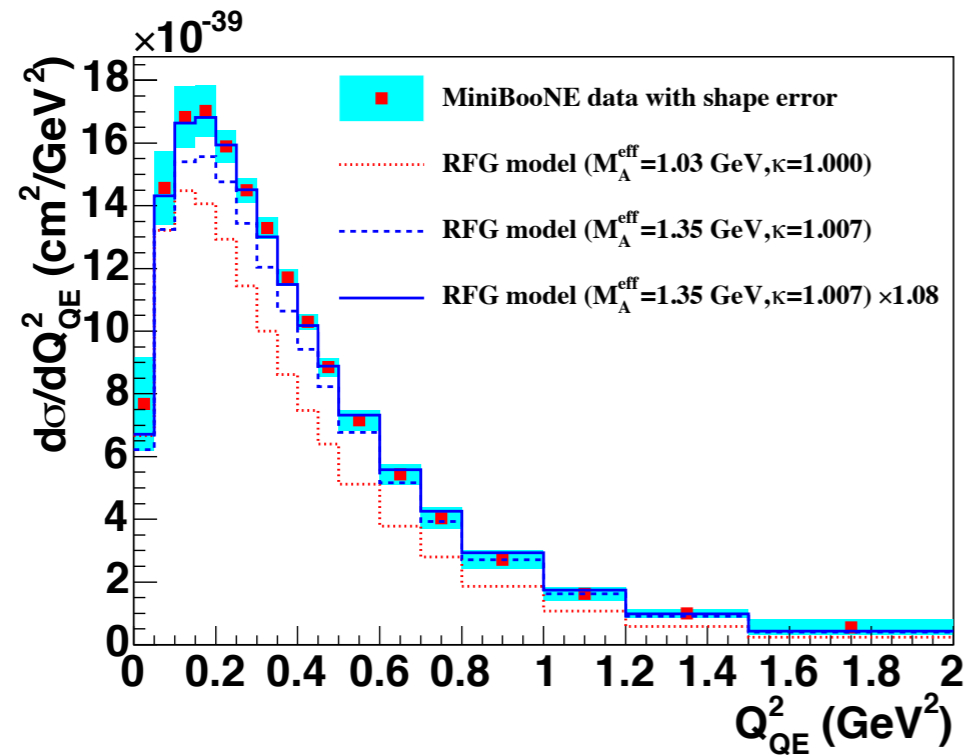
MINERvA on CH

INTERESTING ISSUES

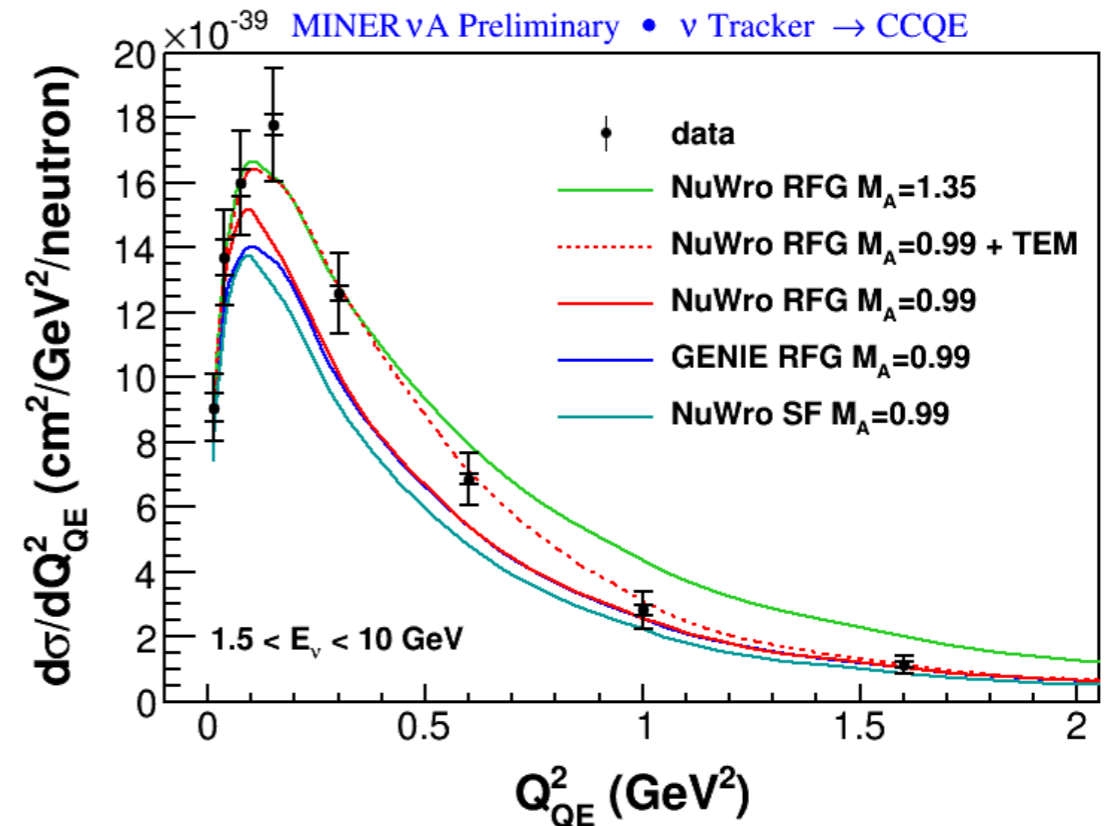
- **Model dependence** of the results: mostly from efficiency corrections
- Complications in the **interpretation of the results** (eg: how much 2p2h do we observe in our data?)

CCQE Measurements

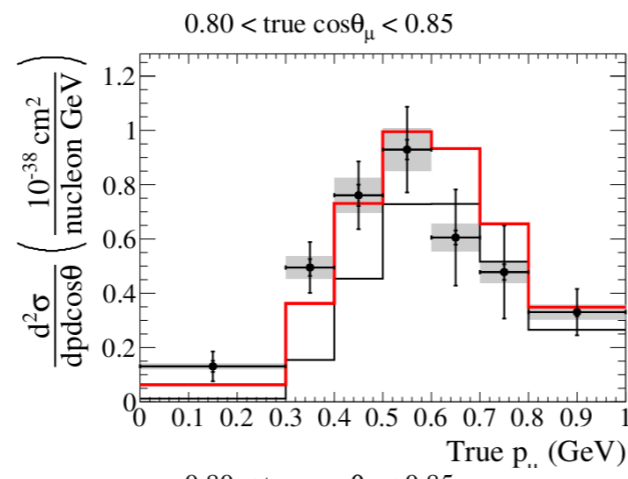
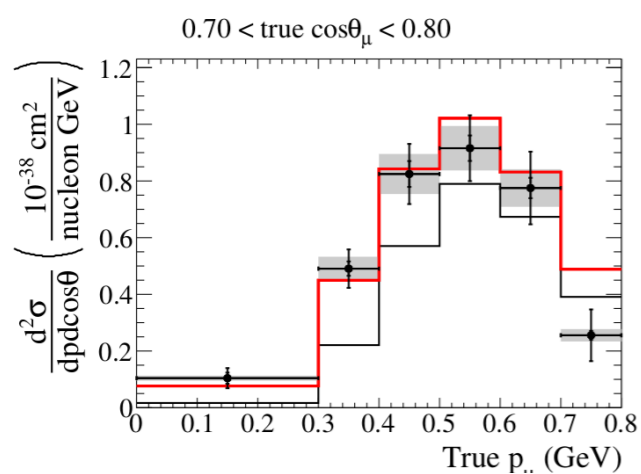
MiniBooNE



MINERvA

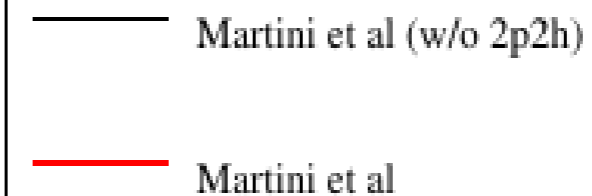


T2K



T2K measurement on CH

arXiv:1602.03652



Model Dependence of Experimental Results?

- Standard equation to measure cross section

$$\sigma = \frac{N_{selected}^{data} \cdot \epsilon}{\Phi \cdot N_{nucleons}}$$

- For each bin of energy the cross section is estimated using the efficiency, where the efficiency is computed from MC predictions:

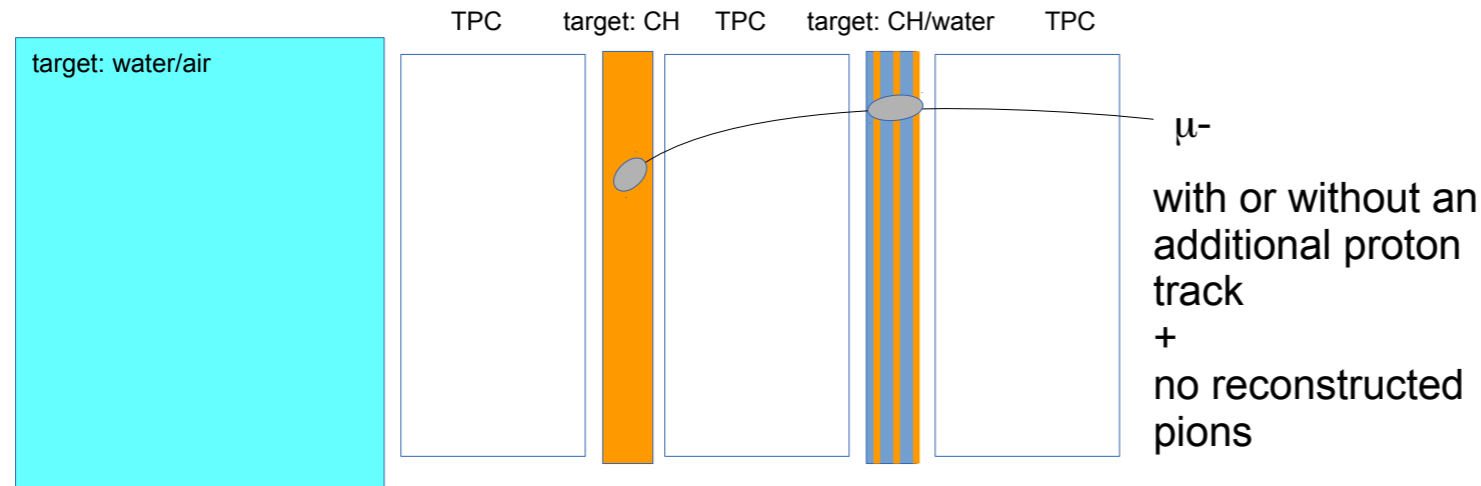
$$\epsilon = \frac{N_{selected}^{MC}}{N_{generated}^{MC}}$$

- The signal definition is important, what are we measuring CCQE, CCQE+2p2h or CCQE 0 π ?
- We cannot measure separately CCQE or 2p2h (especially with only muon kinematics)
- When we consider full CCQE 0 π signal, the efficiency of a given selection may be different for CCQE and 2p2h events
- Efficiency corrections depends on the assumed relative cross sections of 2p2h and CCQE in each bin

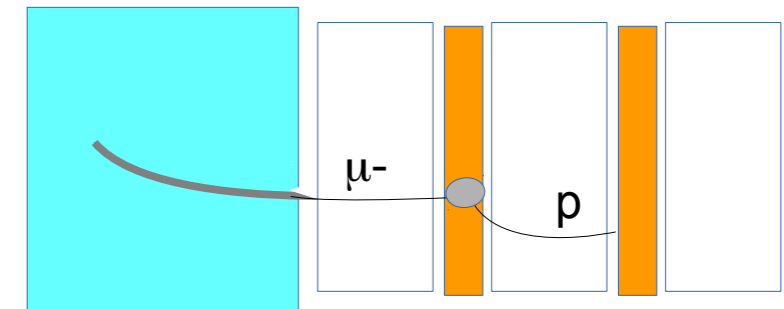
Efficiency Corrections (CCQE)

ND280 has been designed to measure forward-going muons (μ^- and μ^+)
 Our cross-section measurements are highly statistically dominated by such events

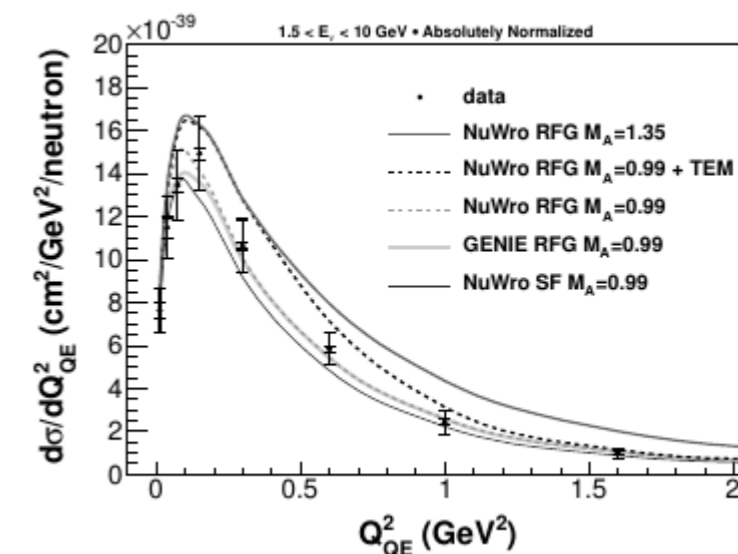
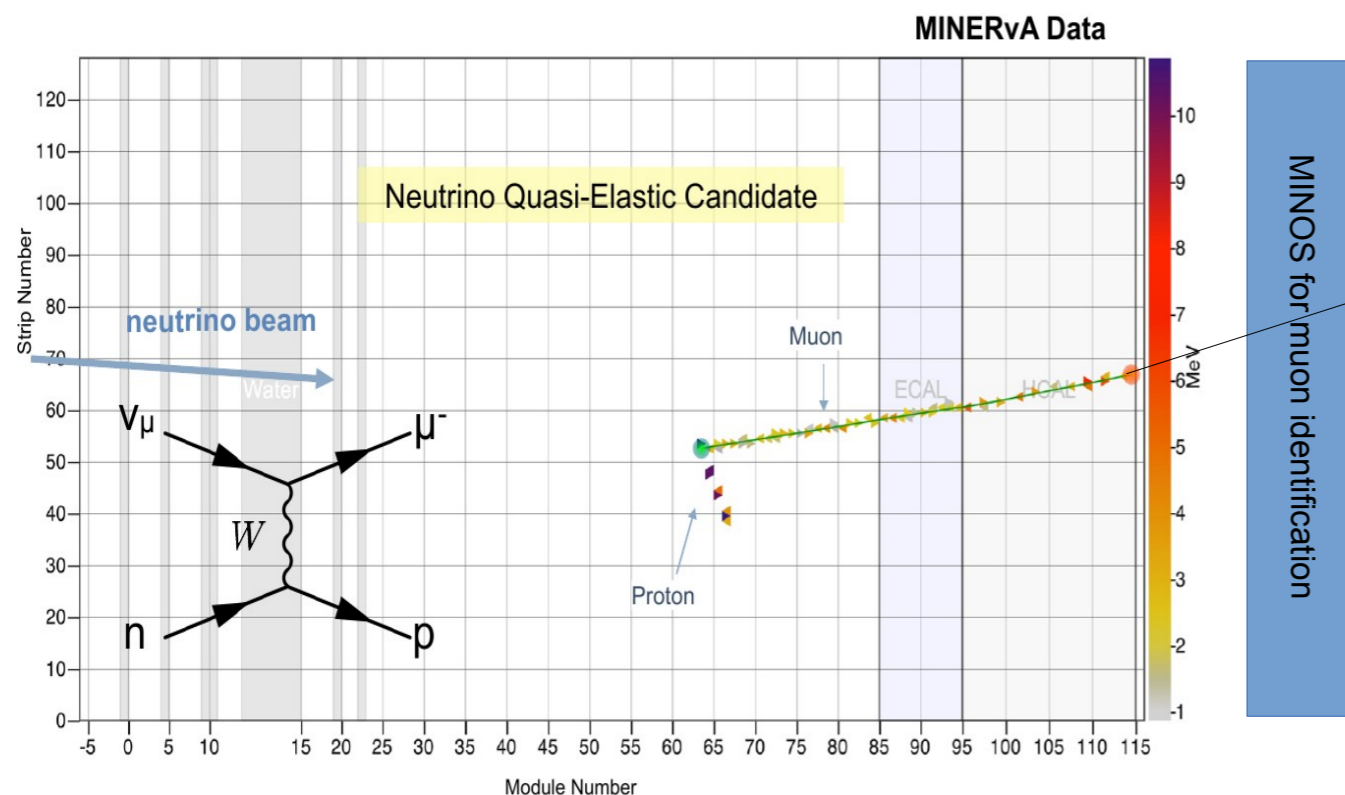
Selection has been modified to recover high angle muons



backward muons

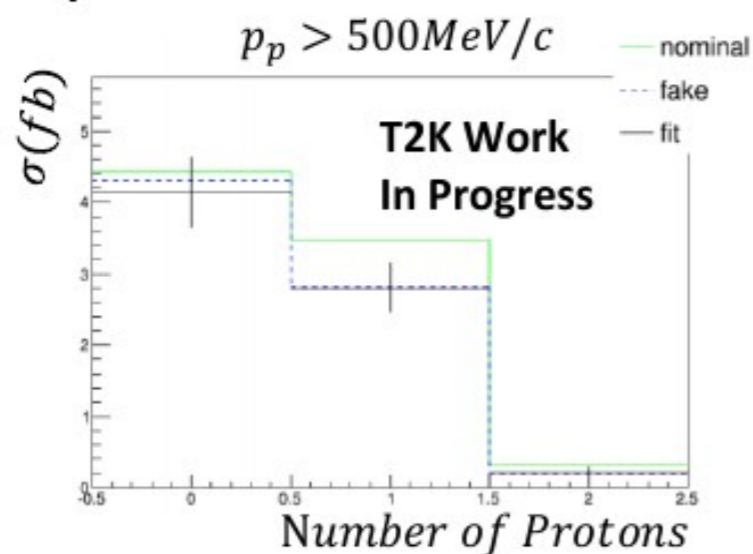


- Efficiency for backward muons was pretty low==>large MC based corrections
- MINERvA uses events with MINOS-matched events

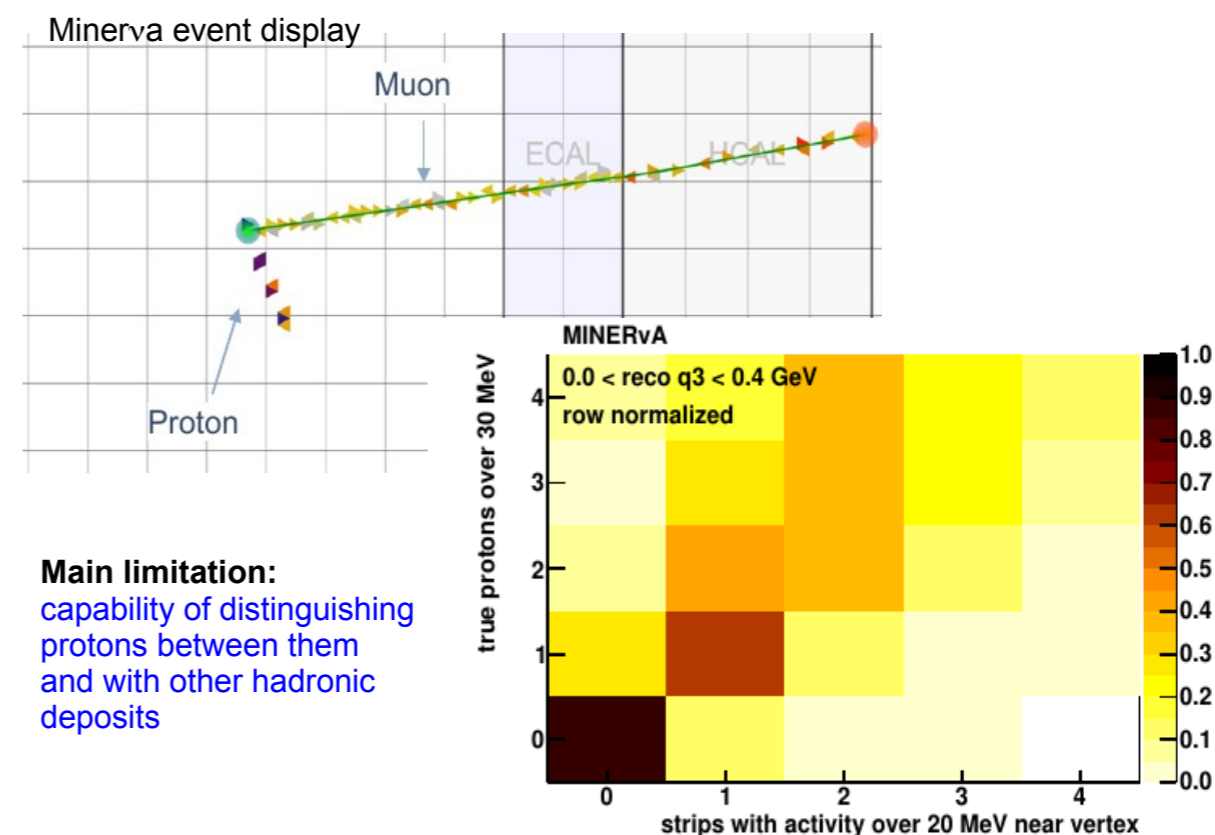


Proton Measurements

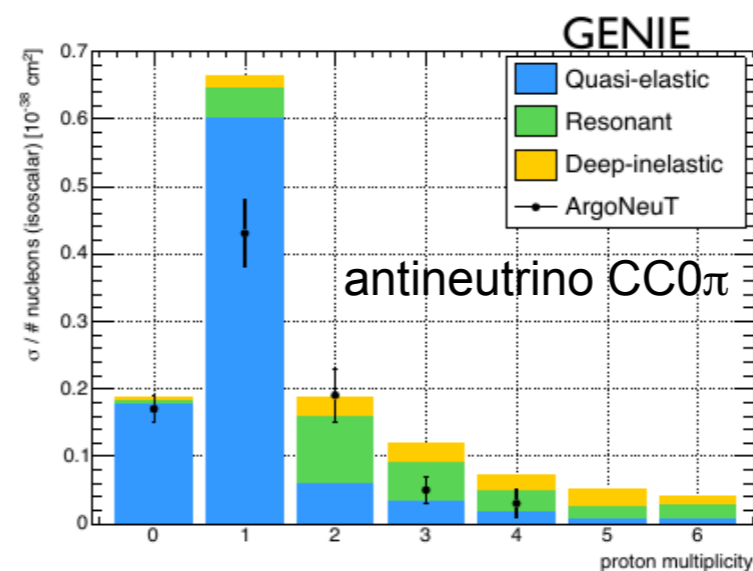
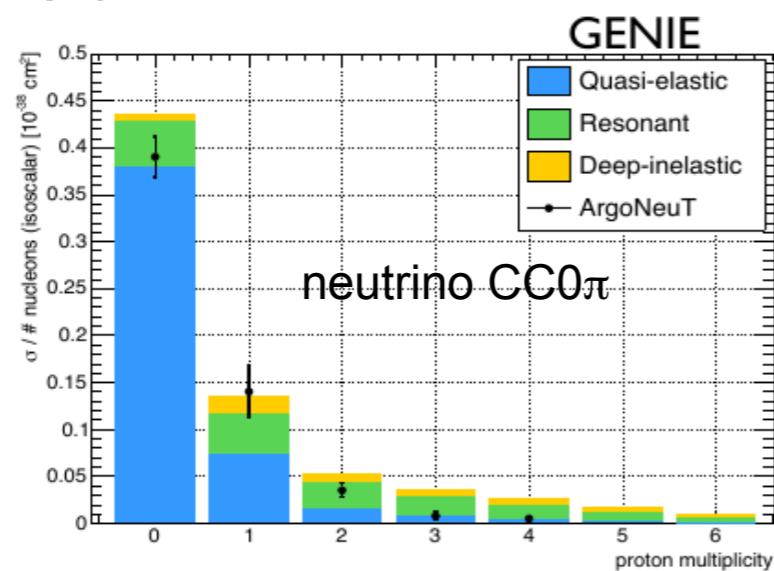
T2K



MINERvA

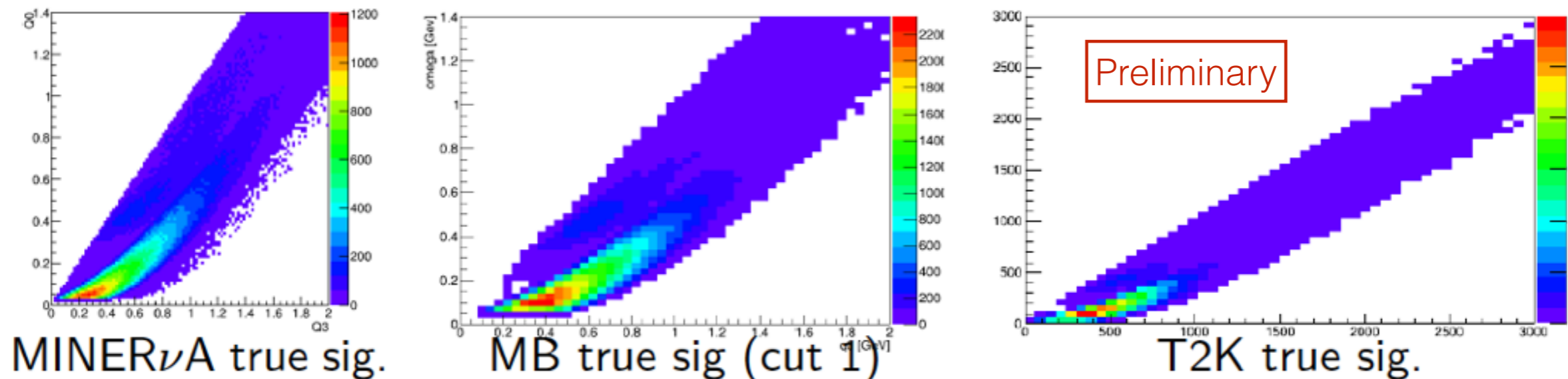


ArgoNeuT

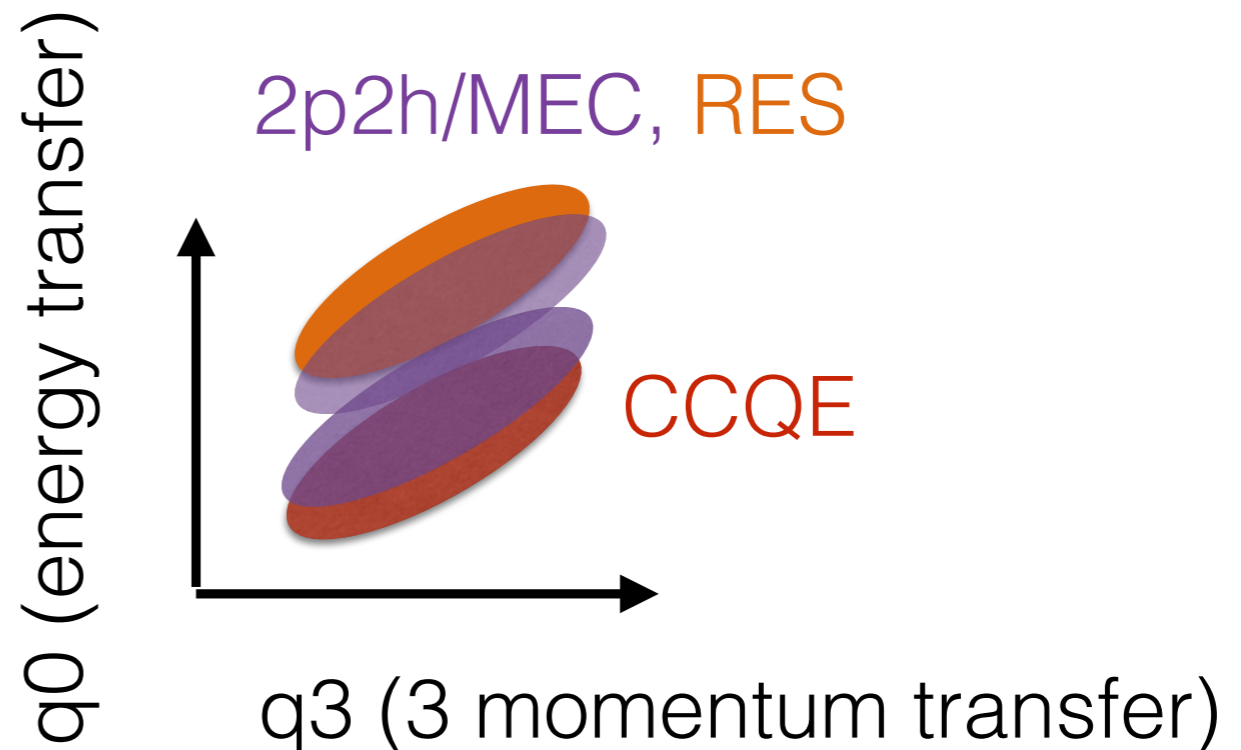


Signal Definitions

Are we measuring the same underlying process?



- For each simulation of the experiment for CC0 π topology
- **All probe similar region prior to selection**



Signal Definitions

- Different experiments have different signal definition
 - MiniBooNE: $CC0\pi$ and $CCQE^*$ (NUANCE)
 - MINERvA: $CCQE^*$ (GENIE)
 - T2K: $CC0\pi$ (NEUT)

- Model independent signal definitions?

$$CCQE = \underbrace{CC0\pi}_{\text{Data}} - \underbrace{n_{pnh}(0\pi) - CC1\pi(+abs) - \dots}_{\text{Generator}} ???$$

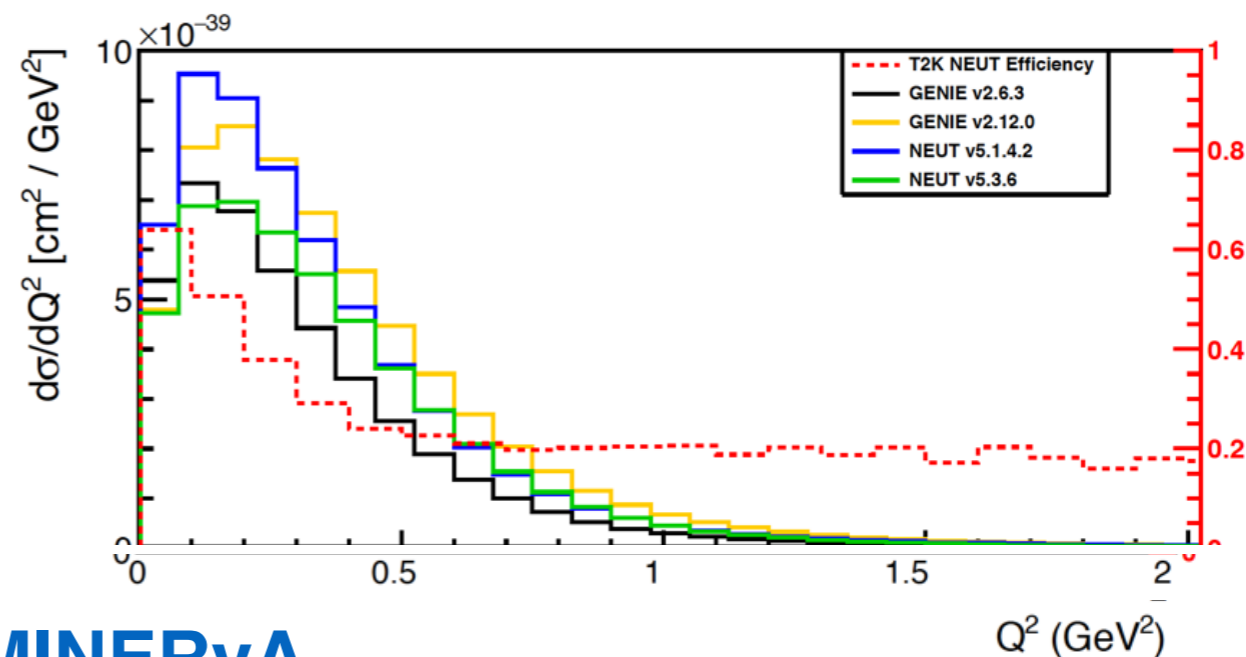
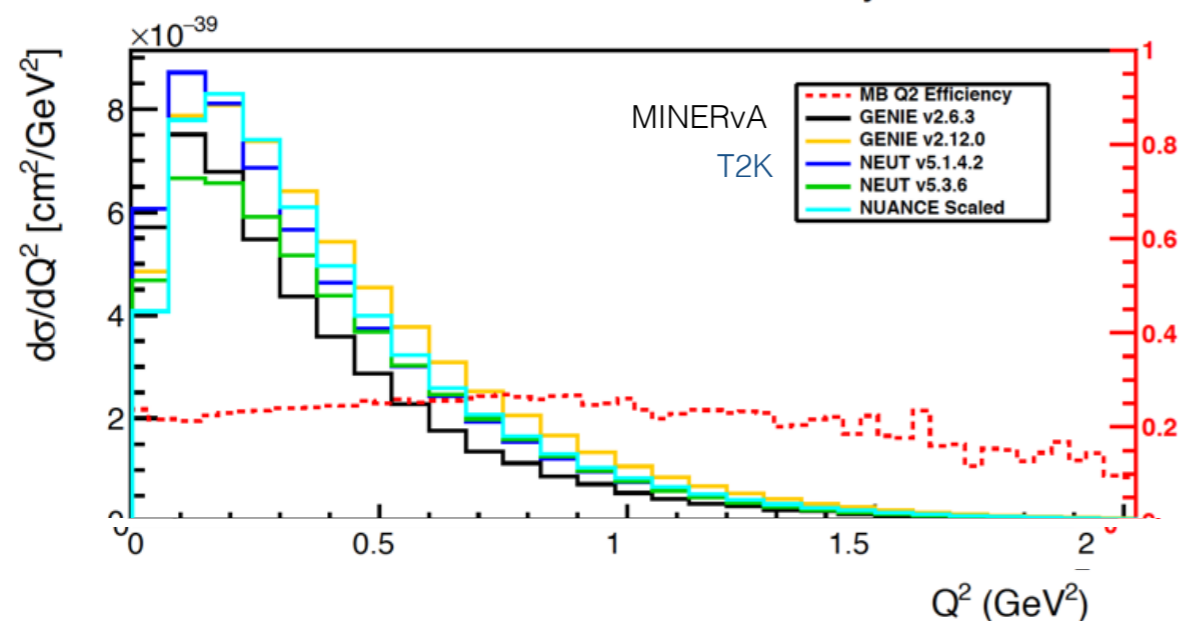
- Tensions: different signal and background definitions
 - Separation chose based on experiment's capabilities and not necessarily easy to unify
- Hard to compare the different measurements

Quasi-Elastic

MiniBooNE

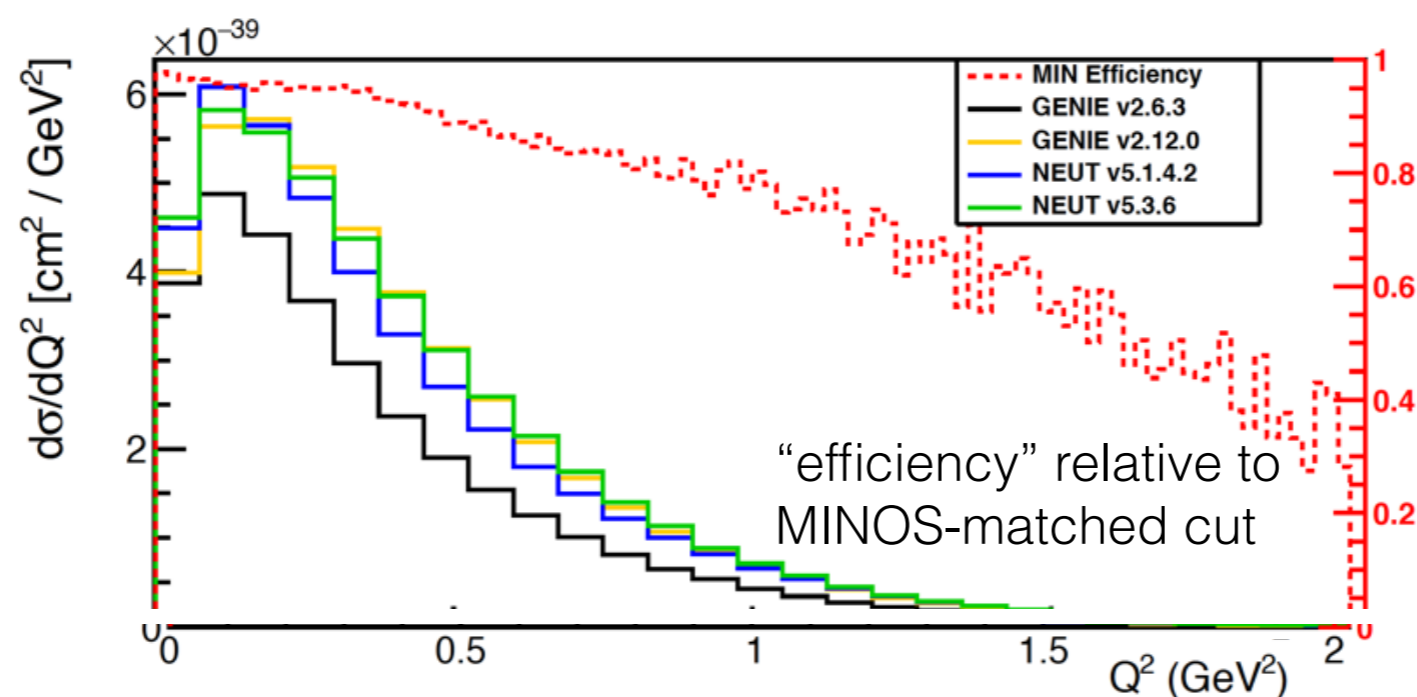
T2K

CC0 π Model & MiniBoone Efficiency in Q^2



MINERvA

CCQE Model for MINERvA Q2 & Efficiency

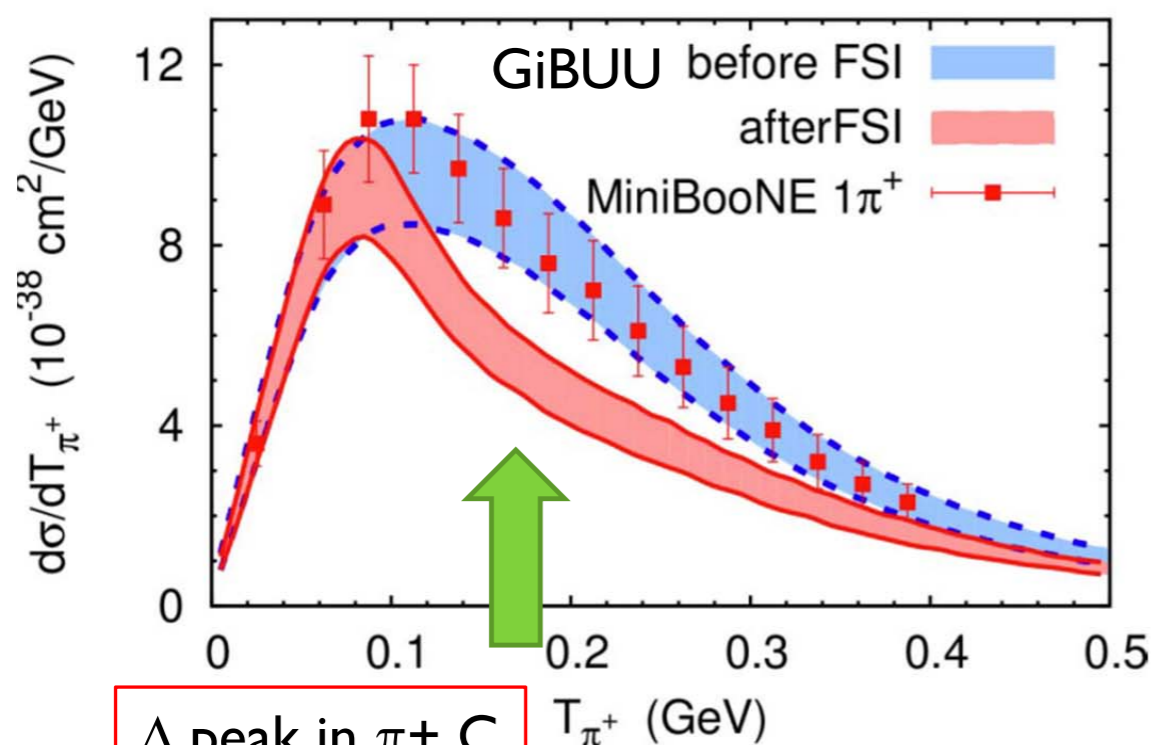


Pion Production

MiniBooNE problem (ν CC1 π^+)

- ▶ MiniBooNE data hard to reproduce, questions FSI models?
- ▶ Very relevant to CCQE-like oscillation signal, new systematic?

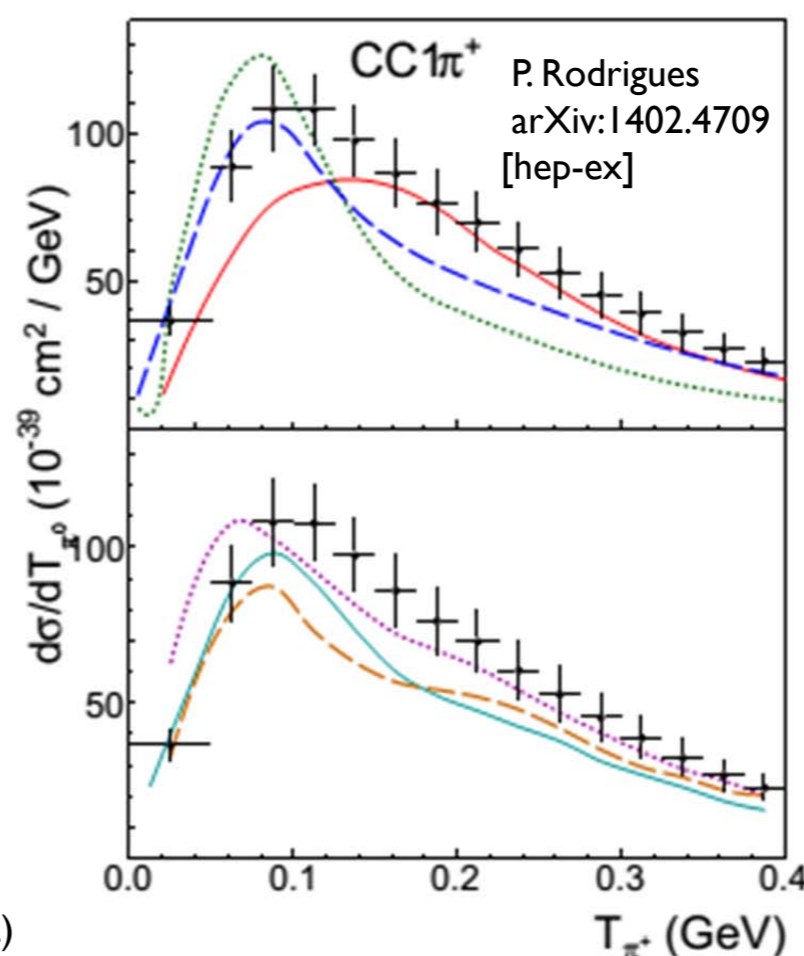
Data at $E_\nu \sim 1$ GeV



GiBUU: O. Lalakulich and U. Mosel, PRC 87, 014602 (2013)

NuWro: T. Golan, C. Juszczak, J. Sobczyk Phys Rev C80, 15505 (2012)

Nieves: E. Hernandez, J. Nieves, M. Vicente Vacas, Phys Rev D87, 113009 (2013)



theory

— Athar *et al.*

... Nieves *et al.*

- - GiBUU

ev gen

— NuWro

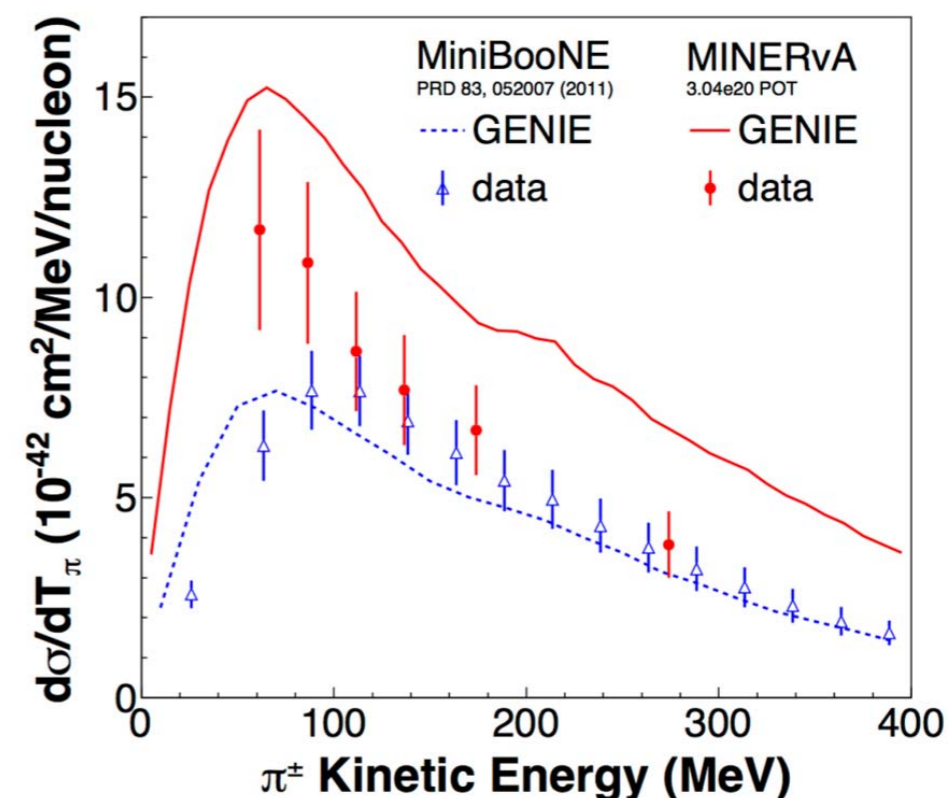
... GENIE

- - NEUT

+ MB data

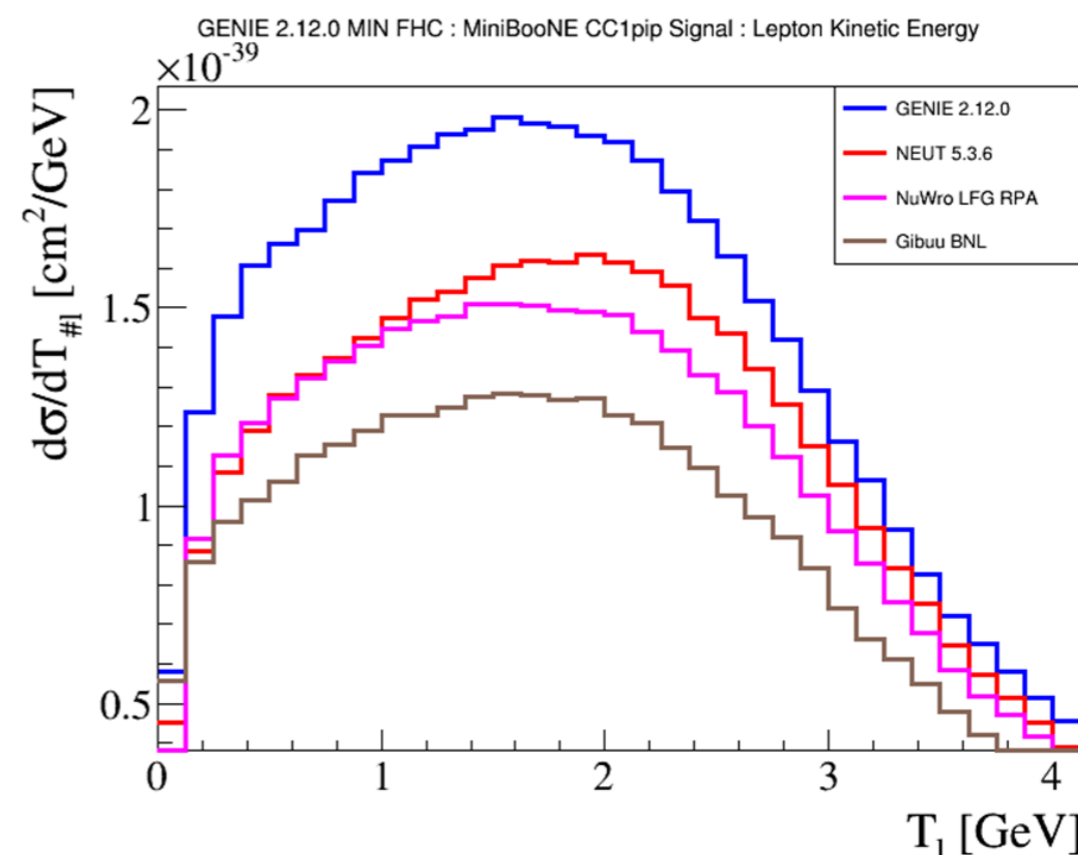
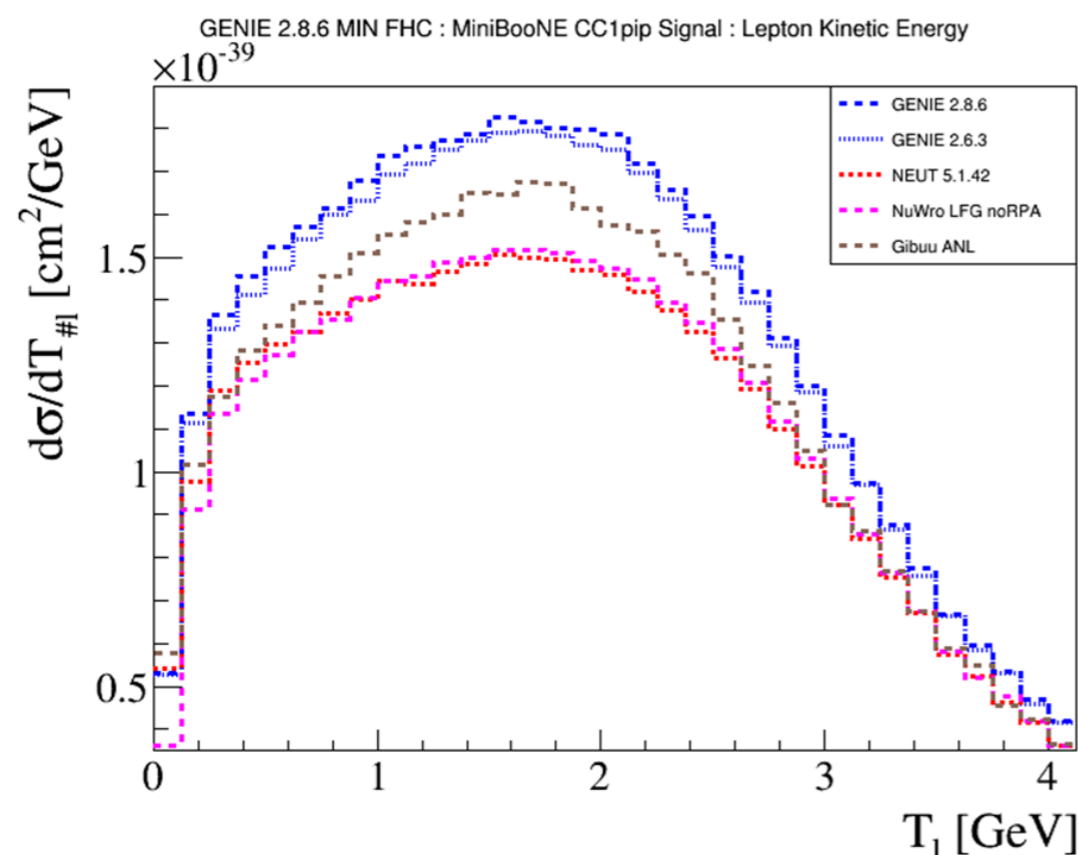
How Well Do MiniBooNE and MINERvA Agree?

- ▶ MiniBooNE - $\langle E_\nu \rangle \sim 1$ GeV; MINERvA - $\langle E_\nu \rangle = 4$ GeV
- ▶ W cuts are different, covered in calculations
- ▶ MINERvA (Eberly and I) tried to design experiment for direct comparison.
- ▶ MINERvA has much larger contribution from higher W, considers it background. MiniBooNE cuts $W < 1.35$ GeV and adds higher W strength (still Δ) from model ($\sim 28\%$ from GENIE)
- ▶ Therefore, need to increase MINERvA data by 28% (and corresponding GENIE calc) for **direct comparison**
- ▶ Shapes are different



Muon Kinetic Energy for Different Models

- Different predictions from each event generator, GENIE, NEUT, NuWro and Gibuu
 - ▶ Indicator of acceptance in key variable
 - ▶ Reflects information in flux and model
 - ▶ Shape changes small with model, mostly magnitude



Models

Model choices

Model	N res	Non resonant	Nucleon Momentum	Δ mods	FSI
Athar	Schreiner-Von Hippel	none	Local Fermi gas	Fit to (γ, π)	Attenuation only
GiBUU	Leitner et al.	Lalakulich et al. - empirical	Local Fermi gas	Fit to (γ, π) Oset	Transport
Valencia	Hernandez et al.	Chiral model	Local Fermi gas	Fit to (γ, π)	Salcedo-Oset (full)
GENIE	Rein-Sehgal	Bodek-Yang (extrap low W)	Global (rel) Fermi gas	none	Effective cascade
NEUT	Rein-Sehgal	Rein-Sehgal	Global (rel) Fermi gas	Via FSI model	Salcedo-Oset (full)
NuWro	Adler (Δ only)	Bodek-Yang (extrap low W)	Global (rel) Fermi gas	Via FSI model	Salcedo-Oset (full)

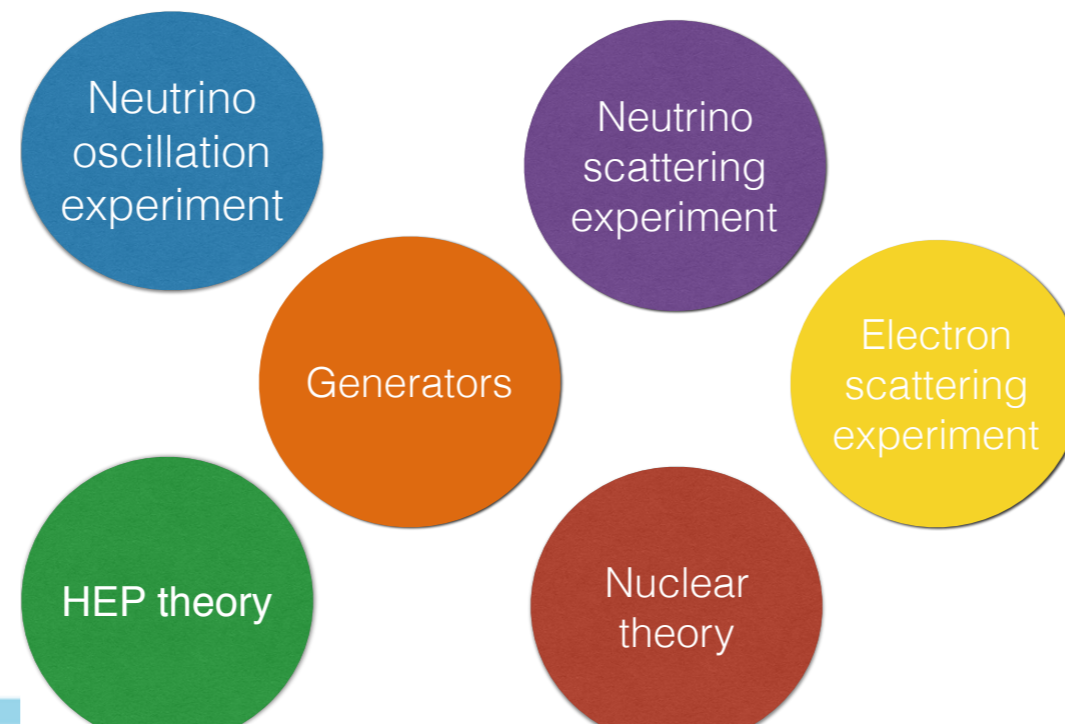
Neutrino Scattering Theory Experiment Collaboration

A collaboration of HEP and NP experimentalists and theorists studying low energy neutrino nucleus scattering

The main goal is to improve our understanding of interactions with nuclei, and get that understanding delivered to experiments (i.e. through event generators)

- Impact on oscillation (long, short baseline) programs
- Impact on cross section measurement programs
- Education and growing the community of involved theorists/experimentalists

A view of the field

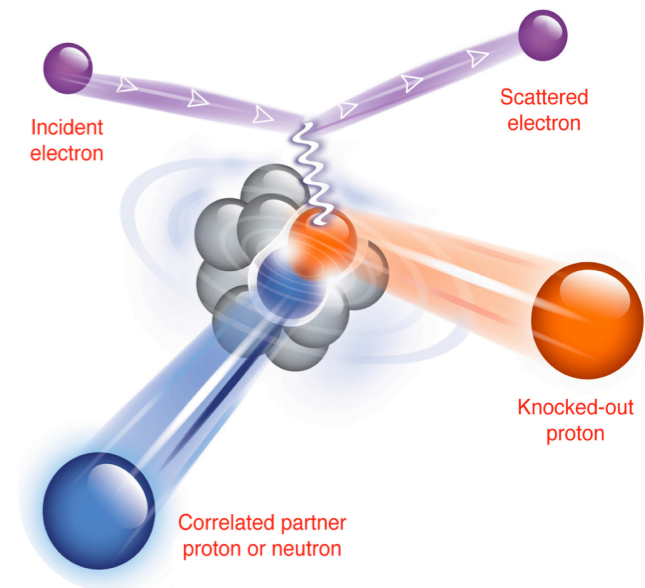
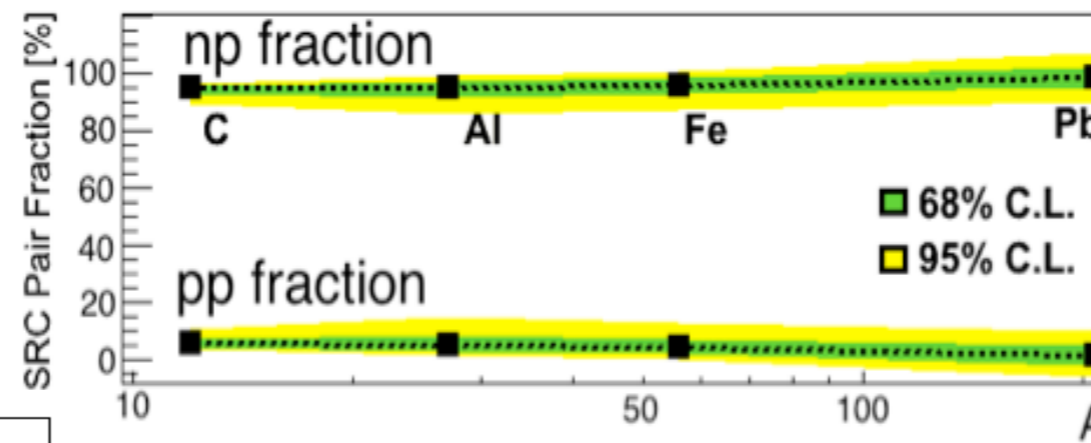


- NuSTEC prepared a white paper to describe what we don't know to motivate where future effort needs to be
 - ◆ **Executive Summary**
 - ◆ **Overview of the Current Challenges in the Theory of Neutrino Nucleon/ Nucleus Interaction Physics – Coordinators: Jorge Morfín and Jan Sobczyk**
 - ◆ **The Impact of Neutrino Nucleus Interaction Physics on Oscillation Physics Analyses – Coordinators: Pilar Coloma and Kendall Mahn**
 - ◆ **Neutrino Event Generators – Coordinator: Gabe Perdue**
 - ◆ **e-A Scattering Input to ν -A - Coordinators: Maria Barbaro and Eric Christy**
 - ◆ **Quasi-elastic, Quasi-elastic-like Scattering - Coordinators: Natalie Jachowicz and Federico Sanchez**
 - ◆ **Coherent and Diffractive Meson Production - Coordinators: Luis Alvarez-Ruso and Jorge Morfín**
 - ◆ **Resonance Model: Coordinators: Steve Dytman and Toru Sato**
 - ◆ **Shallow Inelastic Scattering and Deep Inelastic Scattering: Coordinators: Sajjad Athar and Roberto Petti**

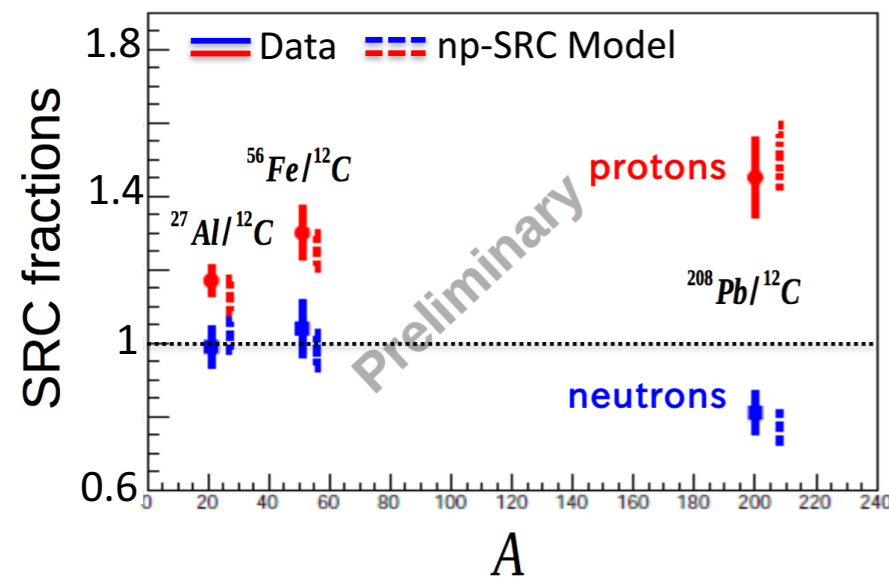
Short Range Correlations in Electron Scattering

- Short Range Correlations (SRC) are pairs of nucleon that are close together in the nucleus
- Beautiful measurements from JLAB:

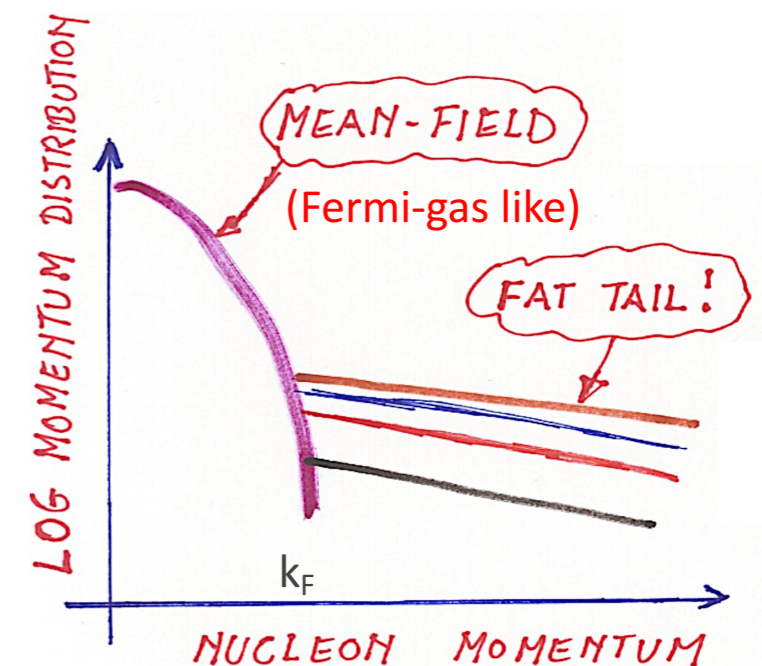
O. Hen et al., Science
364 (2014) 614



Fraction of high-momentum nucleons in asymmetric nuclei



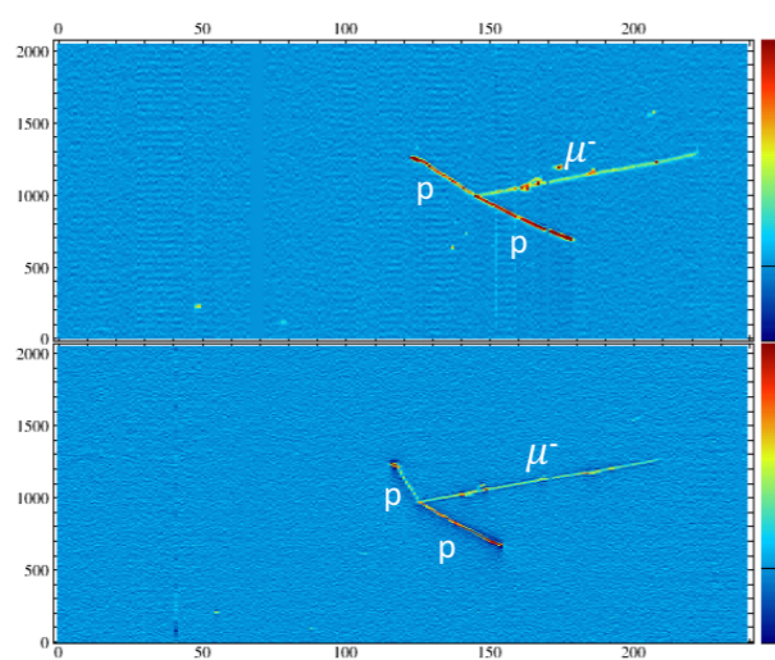
$$\frac{A(e,e'N) [\text{high-}P_m / \text{low-}P_m]}{^{12}\text{C}(e,e'N) [\text{high-}P_m / \text{low-}P_m]}$$



- SRCs account for:
 - ~20% of the nucleons in nuclei
 - 100% of the high-p ($k > k_F$) nucleons in nuclei

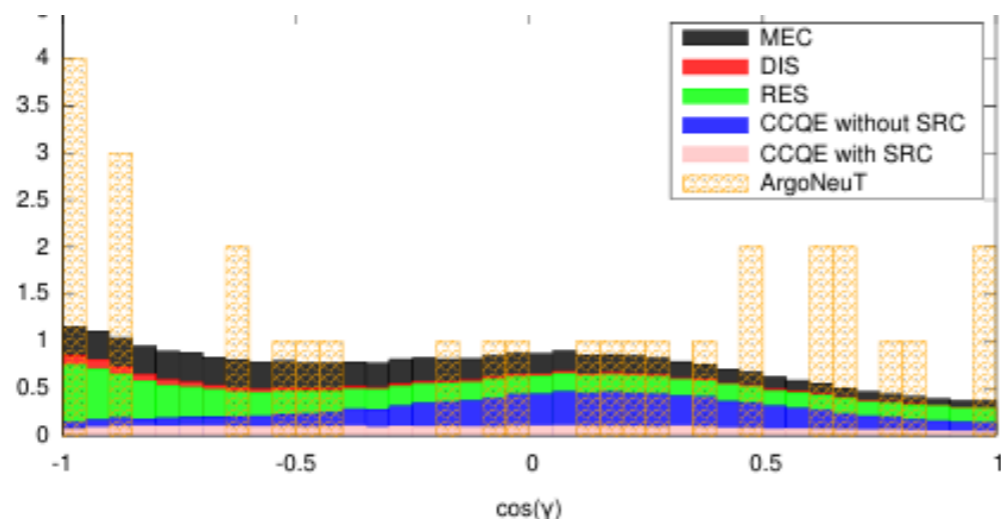
Exclusive Final States

- Jan gave an overview of the NuWro Monte Carlo generator with some details about the final state models: Nuwro uses cascade model for nucleons and pions
- MC studies for the two proton events in the ArgoNeuT experiment



- Motivation: search for SRC nucleon pairs.
- Very low proton reconstruction threshold $P_{thr} \sim 200$ MeV/c, below Fermi momentum.
- Two hints of existence of SRC pairs.
- Four *hammer* events in the LAB frame with almost back-to-back momenta.
- Attempt to reproduce initial two nucleon state (if there is one).
- An access of reconstructed pairs in back-to-back state.

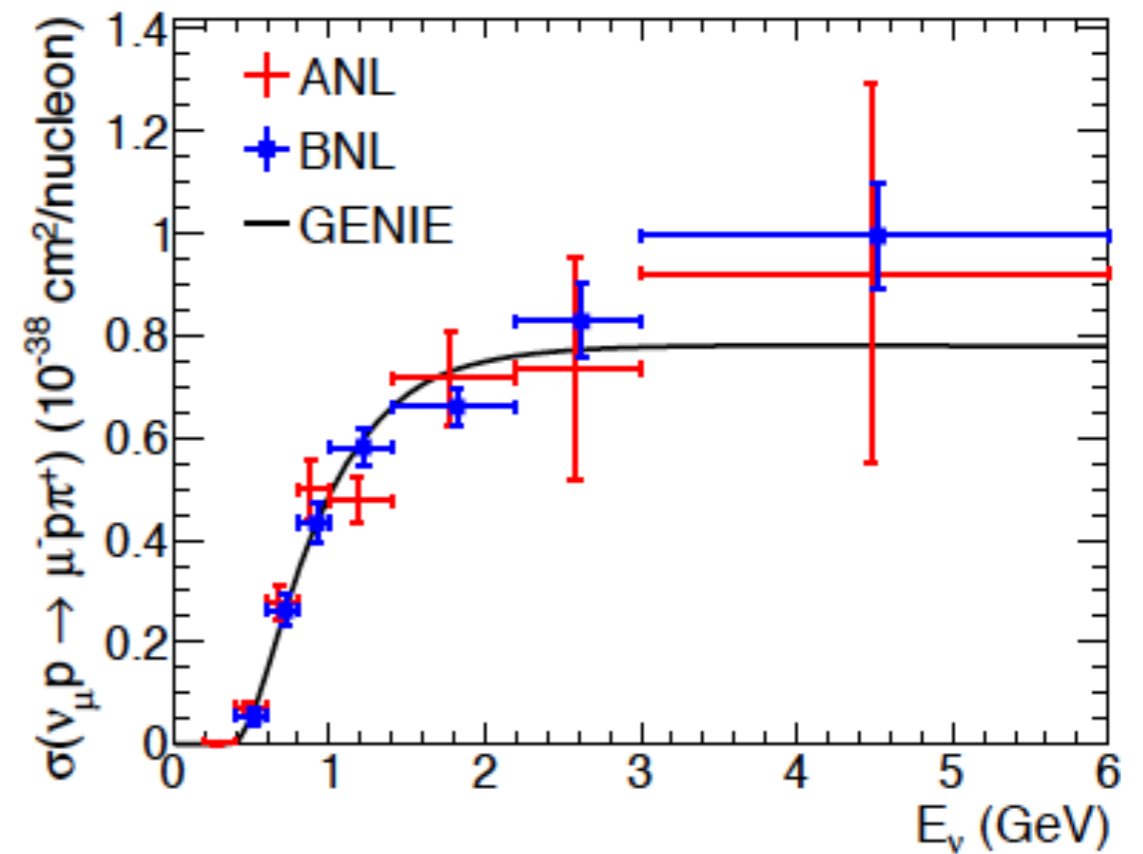
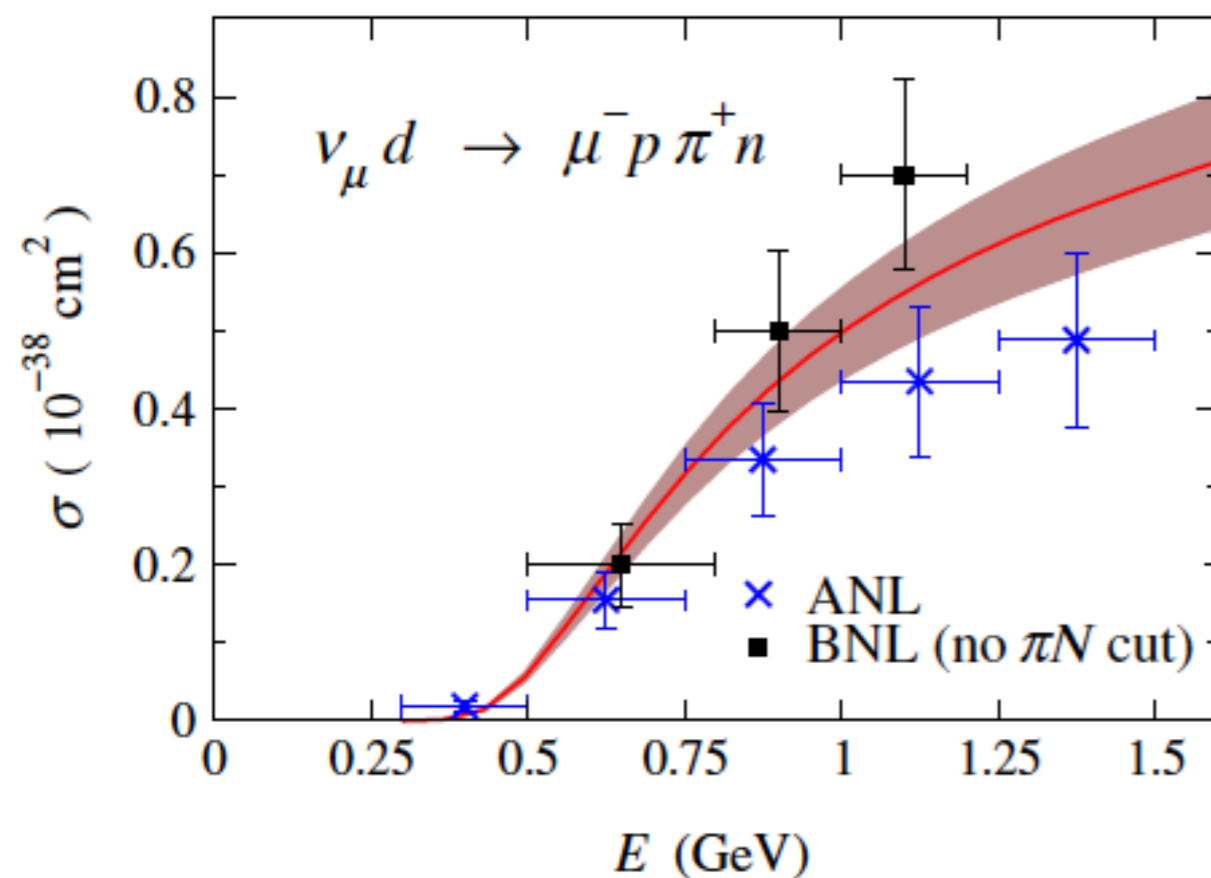
- NuWro predictions:



- NuWro predicts too few hammer events
- The effect is kinematical in nature and tells nothing about SRC pair

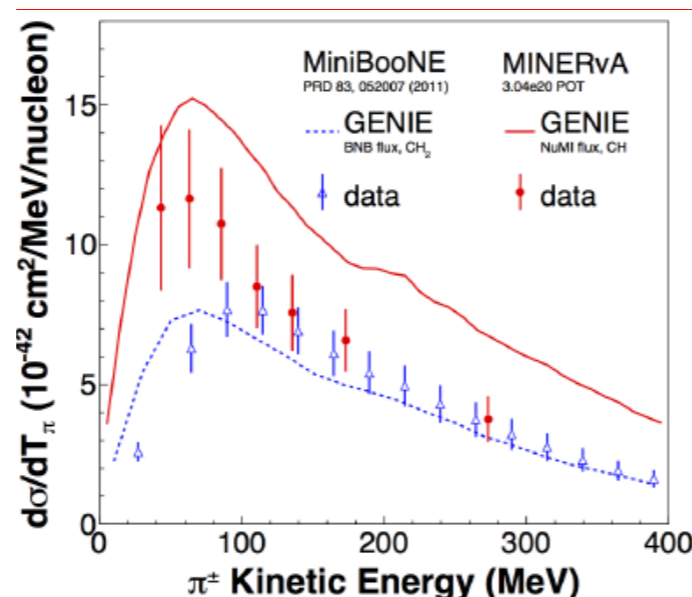
Open Question of neutrino interaction physics (2013)

- ANL-BNL puzzle:
 - Normalization difference between ANL and BNL bubble chamber pion data
- Recent reanalysis of deuterium data finds consistency between ANL and BNL



Open Question of neutrino interaction physics (2016)

- MINERvA and MiniBooNE pion kinematic data are incompatible



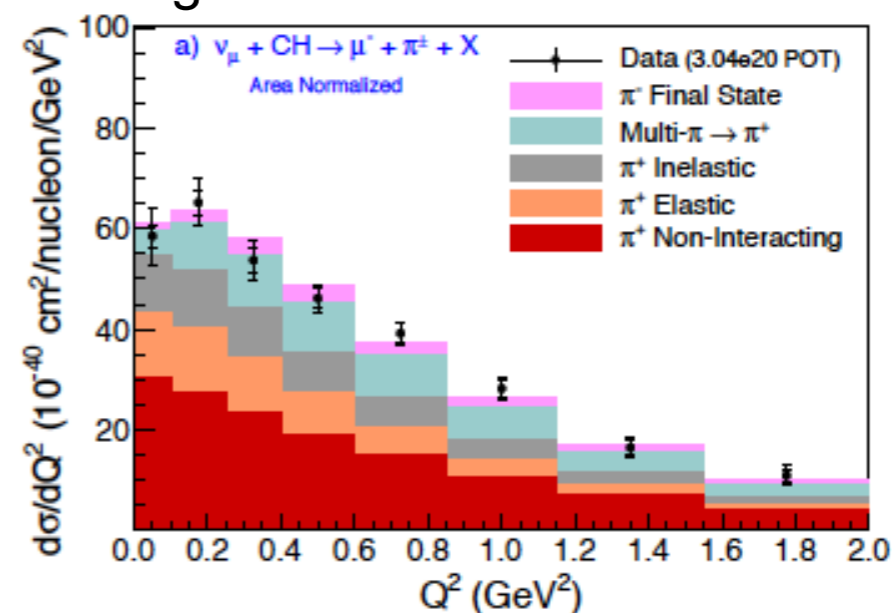
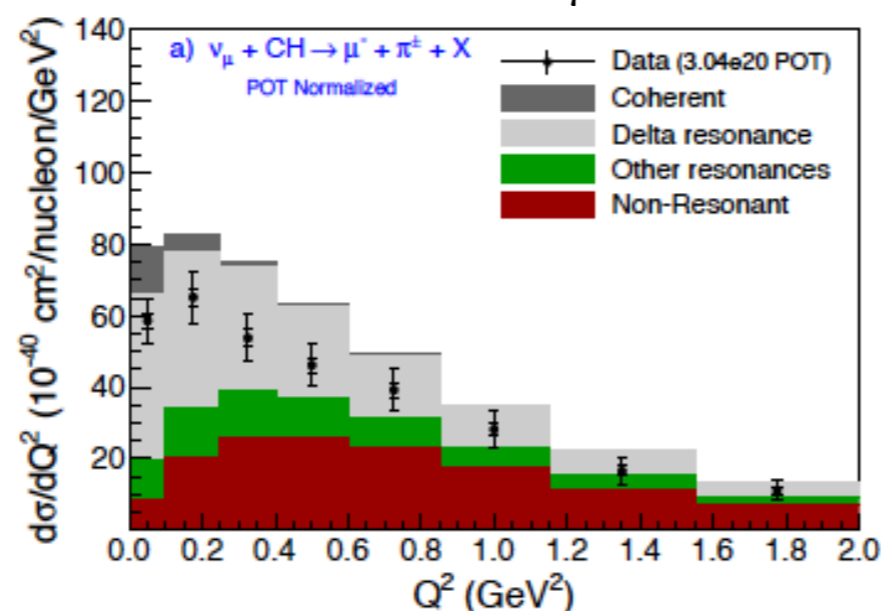
MINERvA ν_μ CC1 π^+ vs. $\bar{\nu}_\mu$ CC1 π^0

- In general, ν_μ CC1 π^+ has shape, and $\bar{\nu}_\mu$ CC1 π^0 has norm agreement with simulation

It's hard to improve data-MC by tuning FSI within GENIE.

Reduce non-resonant background.

Add RPA correction to fix low Q^2 ?



New Measurements (MINERvA)

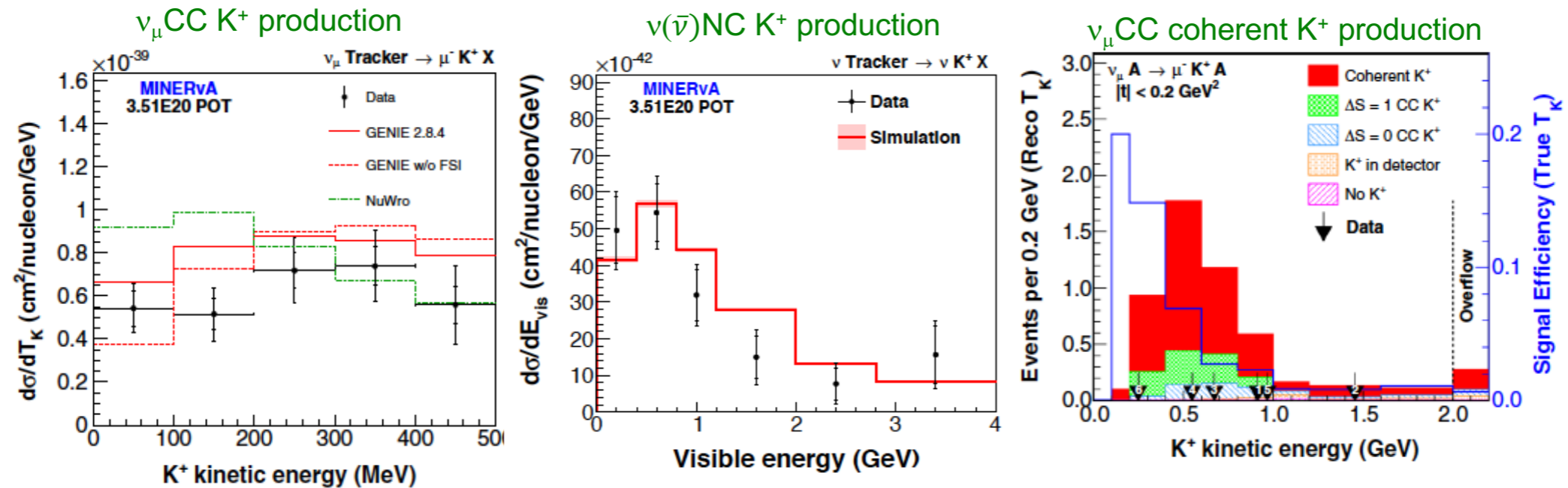
Teppei

MINERvA, PRL 117(2016)111801; 117(2016)061802, PRD 94(2016)012002; 93(2016)071101, arXiv:1611.0222

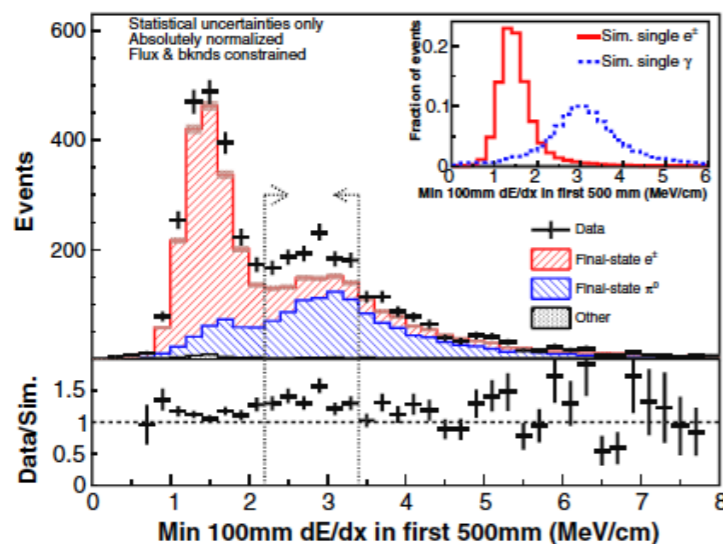
1. Introduction
2. CC0 π
3. Nucleon
4. ν_e vs. ν_μ
5. Pions
6. Summary

5. Other new MINERvA data (now)

Kaon bombs

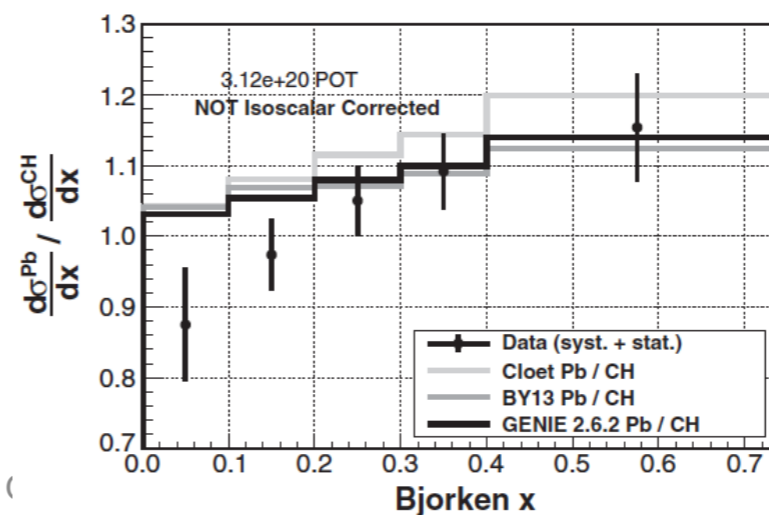


Diffraction pion production



Teppei Katori, (

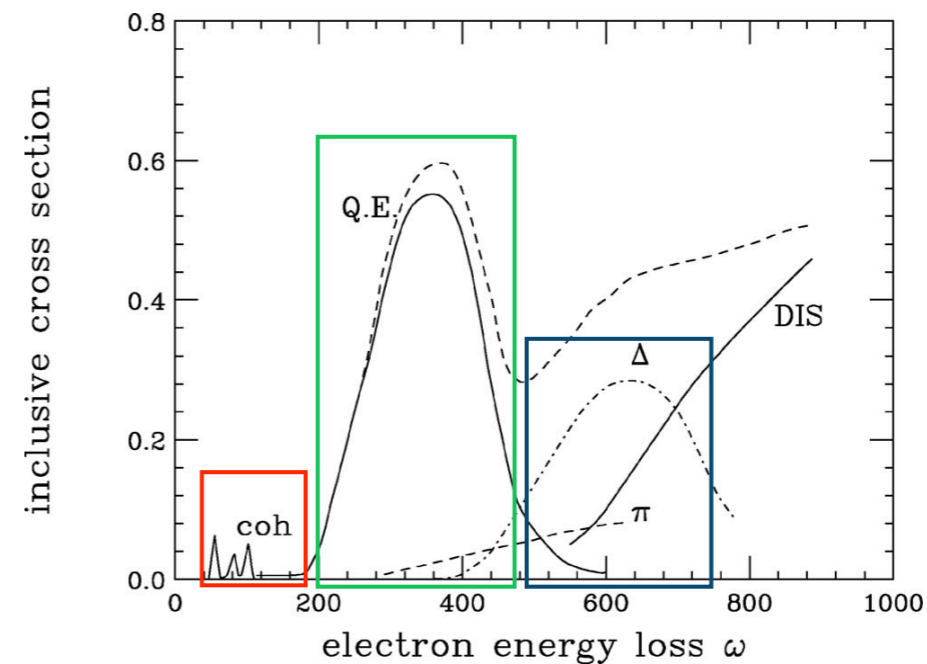
DIS target ratio



58

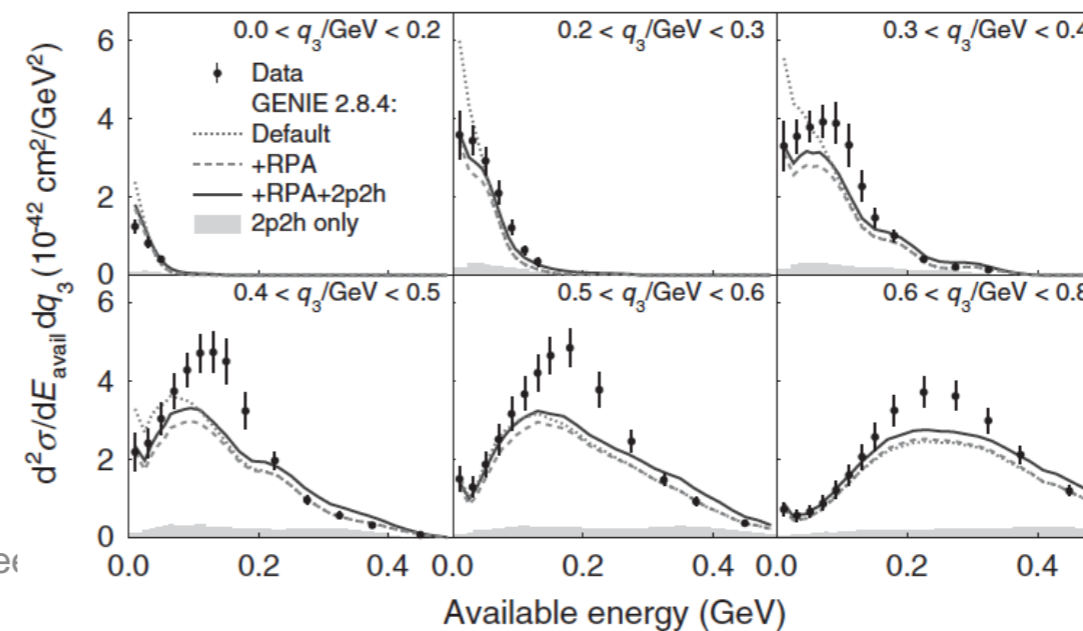
MINERvA reconstruct full inclusive kinematics (which once we thought impossible!)

available energy
(visible hadron energy deposit)
↓
energy transfer
↓
3-momentum transfer



Double differential distribution shows “dip” structure in MC, but not in data

Excess of data around the dip region is very large.



Summary

- Excellent progress in nuclear theory-electron scattering, neutrino scattering experimental measurements and neutrino event generator
 - Understanding quasi-elastic interactions, 2p2h process
 - Many theoretical approaches
 - Implementing 2p2h process on event generator
 - New measurements of electron neutrino scattering
- More connection is needed between nuclear theory and neutrino event generators
- New ideas to analyze electron scattering data to constrain neutrino event generators
- Consensus about making less model depend measurements
- Theory community prefers model independent measurements such as muon angle and momentum, instead Q^2
- DUNE experiment is around the corner, what do we need?
 - From theoretical side: Realistic model description in our event generators
 - From experimental side: more understanding of pion production, nuclear effects, new data from MINERvA, NOvA, MicroBoNE, SBN program is crucial!